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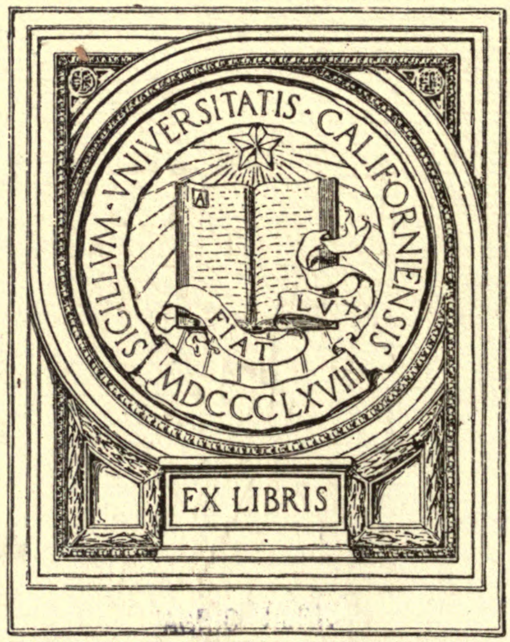
STUDIES ON THE DIURNAL PERIODS IN THE LOWER STRATA OF THE ATMOSPHERE

BIGELOW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WEATHER BUREAU.

STUDIES ON THE DIURNAL PERIODS IN THE LOWER STRATA OF THE ATMOSPHERE.

Reprints from the Monthly Weather Review, February, March, April, May, July, and August, 1905.

BY

FRANK HAGAR BIGELOW, M. A., L. H. D.,
Professor of Meteorology.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

WASHINGTON:
WEATHER BUREAU.
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W. B. No. 344.

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CONTENTS.

STUDIES ON THE DIURNAL PERIODS IN THE LOWER STRATA OF THE ATMOSPHERE.

I.—THE DIURNAL PERIODS OF THE TEMPERATURE.

GENERAL REMARKS.

The following series of papers contains the results of a research into the periodic diurnal processes that take place in the strata of the atmosphere within two miles of the sea-level surface, as disclosed by the data derived from the balloon and kite ascensions made during the past ten years. It includes a discussion of the variations of the temperature, the pressure, the vapor tension, the atmospheric electric potential and coefficient of dissipation of the electric charge, and the diurnal periodic action of the magnetic force. These subjects have been under discussion by meteorologists for many years, but the issue has been so indecisive as to imply that certain important terms have been lacking in the problems, so that it was impossible to come to any definite view regarding the causes and effects in the physical processes. That all these diurnal periods depend upon the effects of the solar radiation in the earth's atmosphere has been evident, but the difficulty of matching together the various lines of experimental evidence derived from observations has been so great that no settled solution has seemed available. The additional data which have been recently secured through observations made in the free air above the ground have, however, altered the point of view in some respects, so that it is believed that the account to be given in these papers describes natural conditions more nearly than has heretofore been possible.

The immediate occasion for undertaking this research consists in the necessity of deciding upon the best lines of work for the Mount Weather Meteorological Observatory, at Bluemont, Va. The organization of so large an institution, dealing with problems in common meteorology, solar radiation, atmospheric electricity and magnetism, made it very important to acquire a clear idea of the relative values of the several types of observation, in order that suitable instruments might be installed and proper observations inaugurated. Since the effects of solar radiation involve many local characteristics which ought to be eliminated before the pure solar terms can be obtained, it was evident that some further knowledge of the diurnal variations of the several elements should be secured if possible, at least to the extent of reconciling the conflicting evidence that the special lines of research have hitherto produced. It seemed the simplest course to make a study of the data furnished by kite and balloon ascensions, and for this purpose the observations at Berlin,[1] Trappes,[2] Hald,[3] and Blue Hill[4] have been studied.

In this paper our examples will be taken from the Blue Hill data as more applicable to the American meteorological field than the European data can be without special consideration. It should be noted that the Blue Hill Observatory furnished the Weather Bureau with certain temperature observations, made at the Valley Station, which were required in the proposed discussion, and for this courtesy our thanks are expressed.

METHOD OF REDUCING THE OBSERVATIONS.

In Volume XLIII, Part III, Annual Harvard College Observatory, Table III, pages 166–214, the data are given for the temperatures on Blue Hill summit, 195 meters, at various heights, and occasionally at the Valley Station, 15 meters, together with the hour and minute of the observation.

(1) The first step in this discussion was to concentrate this material into smaller proportions by taking the mean values where the kites soared at about the same elevation. This gave a new series of data for the time, height, temperature at that height, and temperature at the summit. Corresponding temperatures for the valley at these times were extracted from the observatory records, at the request of the Weather Bureau, so that it became possible to refer the temperature-falls practically to the sea level. It was feared that any characteristic effects of the Blue Hill itself upon the diurnal temperatures, by means of radiation or by convection currents, might prevent the computed temperatures at higher elevations from bringing out the law in the free air with sufficient purity.

(2) A computation of the temperature-fall was next made for each time of observation by taking the difference between the temperature at the height and the valley temperature. A discussion of these temperature differences was preferred, in order finally to obtain the mean temperature at certain selected levels for each hour in the day, rather than to mass together the actual temperature readings recorded at these levels. In the former case the numerical values are less scattering than in the latter, and therefore they are more easily reduced to mean values. If the actual temperatures of the air, in the successive masses associated with the progress of high or low areas over a given station, are employed as the basis of computation, a very large number of observations are required to produce correct normal values in the several strata. The mean temperature falls, on the other hand, added to the normal values at the Valley Station, give the same result theoretically, and this can be obtained much more exactly for a limited number of observations by the method of differences.

(3) The first collection of the temperature differences contained the data applicable by simple interpolation to the levels 15, 195, 400, 600, ... 3800, 4000 meters, or as high as the ascension made its record. The data from the several years, 1897-1902, were collected by months, so that for example all of the January temperature-falls were brought together. They were also arranged by cyclonic and anticyclonic areas, so as to distinguish between the cold southward-directed current and the warm northward-directed current. The former covers generally the areas lying between the centers of the high and low to the eastward of the high, with winds from the northern quadrants, and the latter includes the areas between the centers of the low and high to the eastward of the low, with winds from the southern quadrants. Referring to the subareas adopted in my Cloud Report, chart 9, page 139, they were arranged in the following scheme, marked for convenience H. I=N.W., L. II=N.E., for southward, L. III=S.W., H. IV=S.E., for northward. The subarea for Blue Hill on the date of observation was scaled from the Weather Bureau daily weather maps.

The purpose of this collection was to discover to what extent the diurnal temperature-falls and corresponding gradients in the free air depend upon the cyclonic circulation, that is whether the temperature-fall is different over the cold currents from the north to that over the warm currents from the

[1] Wissenschaftlice Luftfahrten, 1888–1898, Berlin.

[2] Veröffentlichungen der Internationalen Kommission für wissenschaftliche Luftschiffahrt, 1901–3

[3] Travaux de la Station Franco-Scandinave de Sondages Aériens à Hald, 1902–3, L. T. de Bort.

[4] Observations at the Blue Hill Observatory, 1901–2, and appendix of the observations with kites 1897–1902, with discussion by H. Helm Clayton.

south. It may be stated in anticipation of the result that no important difference could be determined from these observations.

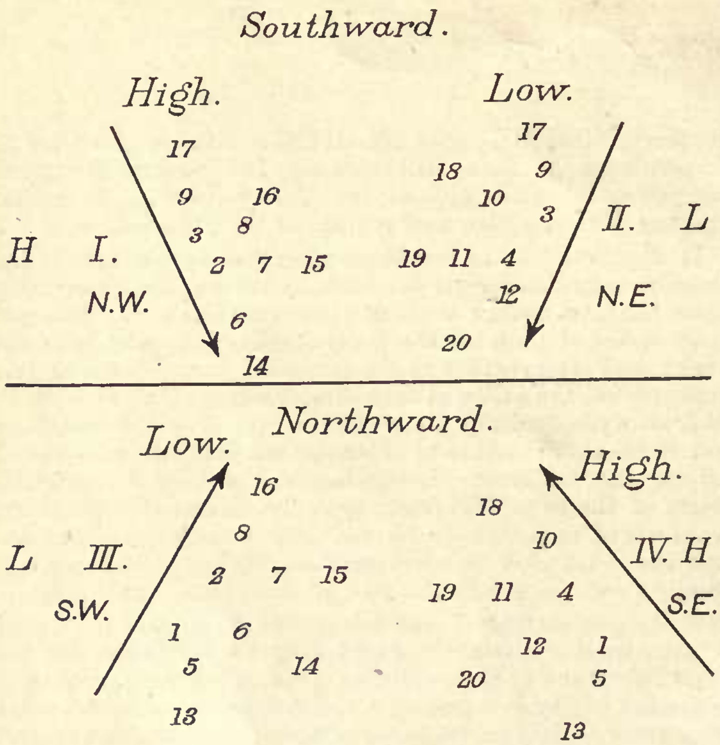


Fig. 1.—Adopted subareas for collecting the temperature data.

(4) In the next collection of the temperature-falls the northward data was kept separate from the southward data, both being computed independently. A further concentration was effected by interpolating the data to the values occurring at the hours 12 m., 1, 2........12 p. m., 1,........ 12 m., for each ascension, and bringing together all the data occurring at the same hour of the day, and as before for each month in the year at the adopted 200-meter intervals. These tables give the respective differences of temperature at each hour of the day, at the heights adopted, in warm and cold currents, and for each month in the year. From this point onward it was necessary to resort to a graphic construction to obtain average values, because the data were not sufficiently abundant at all hours of the day, in each month, for so many levels, to make the result reliable. There may be some question as to the definitive values of the results on this account, but as it was our purpose to obtain a provisional idea of the atmospheric conditions, for the purpose of planning further observations at Mount Weather, we were justified in making as much as possible out of the data in hand.

(5) The individual values of the temperature-fall for each elevation adopted were plotted on sheets, keeping each month separate, so arranged that the ordinates are the differences of temperature between that observed at the Valley Station and the temperature recorded by the thermograph attatched to the kite, the abscissas being the hours of the day beginning at midnight. The data belonging to the southward-directed, or cold currents, were plotted in black and the northward, or warm currents, in red, so that by inspection any systematic difference between these two types could be seen. It may be stated that *no notable divergence between the temperature-falls over the warm and cold currents could be detected*, and we conclude that the warm and cold masses resting on the ground, on either side of the cyclone center, fall off by about the same gradients up to at least one mile, and probably to two miles, in elevation. These masses of air, therefore, preserve their relative independence in the lower strata of the atmosphere, whatever changes may occur in their mechanical structure when penetrating the eastward drift of the higher levels. At the Valley Station itself the actual temperatures were plotted in the same way that temperature-falls were plotted for the several levels lying above it. Mean lines were now drawn through these several groups, or points, to represent as nearly as possible the average values. There was little difficulty in doing this accurately for the hours 10 a. m. to 8 p. m., where data were abundant, but for the remaining hours of the day there was more uncertainty, especially in the winter months, when the number of ascensions was not great. In the levels 195, 400, 600, 800 and 1000 meters, it was possible to construct fairly reliable mean curves, but since the scattering increases rapidly above the 1000-meter level, it was not possible to proceed directly by this method above the 1400-meter level.

(6) In order further to control these average curves and insure an accuracy even greater than could be obtained by simple estimation of the mean position of the curves, the following process was employed. For the hours 12 a. m., 4 a. m., 8 a. m., 12 p. m. 4 p. m., and 8 p. m., the values lying on these curves for the respective hours were transposed to another set of sheets, where the ordinates are the temperature-falls, and the abscissas the month in the year. Thus a rough locus was formed for 12 a. m. or midnight, so that the varying value at that hour for each month in the year might be seen. A curve was then drawn through these points, smoothing down the irregularities, on the theory that the temperature variation constructs a comparatively regular curve in the course of the year. This procedure doubtless tended to fix six points on the diurnal curve at each level with considerable accuracy, and these adjusted points were now transferred back into the preceding set of curves originally derived from the individual observations. The passage from month to month in the way indicated, allowed us to bridge over many gaps in the kite record that could not otherwise have been done. The first set of curves was now readjusted in conformity with these guiding points at 4-hour intervals. The adjustment of fragmentary records by continuous curves crossing each other in two directions as in this case, nearly at right angles, is not only expeditious but usually brings out results very close to the truth, because the mutual adjustment of neighboring points in two directions eliminates the merely accidental errors due to short and imperfect records. This is especially true if some of the fixed points are well established as in these observations during the afternoon hours of the warm months of the year.

(7) For the prosecution of this discussion, whose object it was to eliminate the special local conditions pertaining to the Blue Hill summit, it was necessary to secure accurate normal values of the temperature at each hour of the day, and for each month of the year, at the Valley Station. As these data were not in hand at the Blue Hill Observatory we proceeded as follows:

As stated above, the normal diurnal curves for the Valley Station were computed from the data supplied to the Weather Bureau at the times the kites were flying. Also, the normal diurnal temperatures for the summit were supplied from the records of twenty years, 1885-1904, which were accurate. By the computations above described for the temperature differences between the summit and valley, inasmuch as the amount of data was sufficient, we had reliable corrections which, applied to the summit normal temperatures for each hour, gave the corresponding values at the Valley Station. These were compared with the diurnal values obtained on the days of kite ascensions, and from their combination certain surface temperatures were found upon which the temperatures computed in higher strata were made to depend. Any inaccuracies pertaining to the final results derived in this manner can be eliminated by further direct observations, but it will require a

very large number of additional ascensions to accomplish any such purpose.

(8) We can impose upou this data yet another mutual adjustment. Up to this point the several curves for each month have been kept entirely independent of one another up to 1400 meters, but they were now brought together on sheets, one for each month, by transferring the several curves to the same set of axes of ordinates and abscissas. The successive curves in elevation now took positions appertaining to their respective temperatures differences. This can be seen by inspecting the curves of figs. 2-13, "Temperature-falls in the the lower strata, Blue Hill kite observations 1897-1902." In the lower levels 195, 400, 600, 800 and 1000 meters, there is great divergence in the shape of the curves, but they gradually approach a typical form which must be eventually that of the temperature curve at the surface itself. This is evident from the fact that at some elevation the diurnal variation proper of the temperature ceases to be effective, and since the temperature-falls were measured from the surface curve, the same curve must appear at those levels which have no true diurnal variation of their own. The difference between the surface curve and the computed curve at any given elevation gives the variation belonging to that level. The elevation at which the diurnal variation really disappears for each month in the year was not known, and could not be determined from the observations. It must be lower in winter than in summer, and I have merely assumed an average of 3400 meters. In case this is not correct, it yet is evident from the formation of these curves up to 1400 or 1600 meters that it has become a comparatively small quantity and that a change in the elevation from 3400 meters will have little effect upon the conclusions which we required in this series of papers, since they pertain to the strata up to only 2000 meters.

(9) The kite ascensions in several cases extended up to 3000 or even to 4000 meters, and by studying the computed table of temperature-falls it was not difficult to select the temperature-fall applicable at the 3400-meter level for each month. These were plotted in an annual curve, and the smoothed values were adopted for further use. At the value determined in this way for 12 m., or midday, as the temperature-fall for the month, the mean diurnal temperature curve of the Valley Station was plotted, and it is seen as the uppermost curve of the system marked 3400. We had already carried the other set of curves up to 1400 meters, and it was proper to suppose that the gradient system changed by regular steps between these two elevations. A study of these curves from month to month will, I believe, lead to the conviction that they are a very close approximation to the mean temperature-fall system in the lower strata which would be derived from a very long series of ascensions.

RESULTS OF THE DISCUSSION.

The system of curves, figs. 2–13, "Temperature-falls in the lower strata, Blue Hill kite observations, 1897–1902," contain the final results of this discussion. The chief point of criticism, as already mentioned, is the adopted height, 3400 meters, at which the surface curve should be located. The interpolation between this curve and the 1400-meter curve will be a little different if the topmost curve should preferably be placed at an elevation lower or higher than the one adopted, which is about two miles above the summit of Blue Hill. The most conspicuous feature of these curves in each month is the relative forms of the curves at 195, 400, 600, and 800 meters, which indicate that the temperature-falls are very different in the successive lower levels. By taking the differences between any two curves of the system the mean temperature gradient can be readily computed. Another striking characteristic is the persistent inversion of temperatures in the hours from 10 p. m. to 5 a. m., especially in the lower levels up to 1000 meters. This is seen by the ordinates being drawn with a positive sign, or downward on this scale of ordinates. The midday maximum temperature-fall can be seen to occur at an earlier hour in the lower levels, as 12 m. to 1 p. m., and at a later hour in the higher levels, as 2 to 4 p. m. The maximum rate of variation is quite uniformly located in the morning hours at 6 to 10 a. m. for rising temperature and at 5 to 9 p. m. for falling temperature. An examination of the curves from month to month shows that there is a general increase in the amplitude from winter to summer. At the same time, in the winter months the amplitude for the lower levels, 600 to 1000 meters, is greater than for the upper levels; on the other hand, in summer the amplitude in the lower levels is less than in the higher levels. The transition months, April, May and September, October, have about equal amplitudes in each level. The fact that this subtle law has been deduced by the method of computation employed speaks strongly for the efficiency of cross-plotted adjustments.

I have used the same method in deducing the temperatures of the atmosphere up to 16,000 meters, charts 78, 79, International Cloud Report, and in determining the temperatures under the Rocky Mountain Plateau at sea level, chart 13, Barometry Report, and in other places. It is the only satisfactory way to adjust broken series of incomplete data to an approximate mean, such as can be secured otherwise only by a very great number of direct observations. Several other important relations will be found in the other papers of this series which tend to confirm these conclusions. It may also be further noted that there seems to be a semiannual period in the positive or the inversion ordinates in the morning hours 2 to 5 a. m., as well as a rearrangement in the order of heights at which this is greatest. Thus, the amplitude for the 4 a. m. hour of the 400-meter curve has a single period, with maximum in February and minimum in October; the 600-meter curve, however, has a maximum in February and another maximum in June, with minima in April and October; the 800-meter curve has two maxima and two minima in agreement with the 600-meter curve. The 195-meter curve at the summit of Blue Hill shows that the temperatures at the summit and base, 15 meters, do not vary in parallel, and hence the gradient system referred to the level of the open country will differ somewhat from that referred to the summit. This should be remembered in the use of the gradients of the Blue Hill Observatory Report.

We have now obtained the material necessary for deducing the mean (approximate) temperatures at the different levels, by merely adding algebraically the temperature-falls to the normal temperatures of the Valley Station. The results are given in the tables, figs. 14–25, "Blue Hill temperatures in the lower strata." The ordinates of temperature have been plotted to decrease upward, in order that they may conform to the actual conditions in the free air, where the temperature diminishes generally with the height. There are several results of unusual interest to meteorology which appear on the face of these charts. The first is the remarkable distribution of temperature in the levels from 600 meters upward as compared with the surface temperatures. In the winter months—December to March, inclusive—there is a pronounced inversion of temperature throughout the day, so that the night hours, 7 p. m. to 5 a. m., are warmer, while the day hours, 6 a. m. to 6 p. m., are colder than the mean for the day at the several levels. It seems very remarkable that in the hours of full sunshine the effect of the radiation on the temperature of a stratum of air should be to allow it to remain cool rather than to heat it. Evidently the result comes about indirectly, by reason of the fact that the incoming short-wave radiation has little influence directly on the temperature, because there is not much absorption. These short waves impinge upon the surface of the earth, which becomes a radiating body of low

temperature and emits long waves. These are strongly absorbed according to the prevailing physical conditions, as the relative amounts of dry air and aqueous vapor, coefficients of absorption for different wave lengths, and so on. Convection currents also enter into the result, and, indeed, the complex function here displayed requires much careful examination before further conclusions can be stated. The temperatures diminish generally with the height after leaving the 400-meter level, but the diurnal period gives a maximum of cold at midday and a minimum about midnight. In the summer months, on the other hand—June, July, August—the inverted temperature distribution does not exist relatively to the surface, but the curves are all of the same general type, with a maximum temperature in the late afternoon, and minimum in the early morning. In the transition months—April, May, September, October, November—the diurnal temperature curve has two maxima, 8 a. m. and 8 p. m., and two minima, 2 a. m. and 2 p. m. The process of transition can be followed in the several levels from month to month, and it is a very interesting phenomenon.

The second important feature of these curves is the building of a semidiurnal period in the temperature at the elevation 400 to 600 meters, in all months in the year, with the maxima at 8 to 9 a. m. and 8 to 9 p. m. They are seen very distinctly represented in May and September, where they are formed up to the very top of the diurnal disturbance. The single diurnal period at the surface is replaced by a double diurnal wave at 400 meters, and this appears quite plainly in every month except July, where it probably is nearly extinct. In the higher levels, above 800 meters, there is a tendency for the double periods to contract the maxima from the 9 a. m., 9 p. m. hours nearer toward midday, and form two crests or a single crest near midday, especially in the winter months. It will be shown in the next paper of this series that those superposed temperature waves, having their maxima disposed as just explained, are competent to produce the diurnal variation of the barometric pressure in the single, double, and triple components, into which the observed pressure at the surface is usually resolved by the Fourier Series of Harmonics. Mr. Clayton has obtained similar curves of temperature at 500, 1000, 1500 meters, as shown on fig. 5 of his paper on "The diurnal and annual periods of temperature."—Annual Harvard College Observatory, Vol. LVIII, Part I, 1904, though they are composites of the several curves really belonging to different months of the year. It will be seen from my curves that mean annual values computed from observations taken in all parts of the year are correct only for certain limited intervals, in which the varying temperatures pass through such special values. Similarly, discussions of all data depending upon mean values made up in this way can have only a limited application in deducing daily free air temperatures throughout the year. This disclosure of the fact that the temperature curves differ according to the elevation from the one observed at the surface opens up the possibility of explaning not only the semidiurnal and triple diurnal barometric waves, but also the movements of the ions in the atmosphere in their relation to the electric potential gradient, the coefficient of neutralization and number of ions in the connection with other meteorological phenomena, and the variations of the diurnal magnetic field in all latitudes of the earth. These researches will be explained in the other papers of the series.

Fig. 2. January.

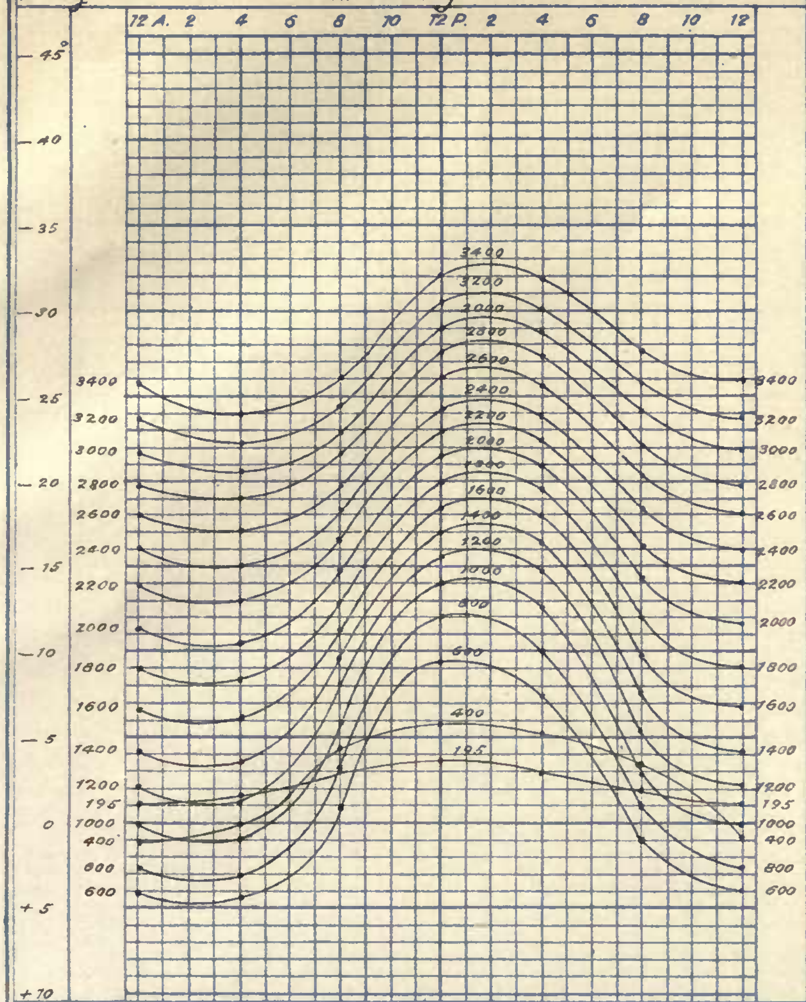


Fig. 3. February.

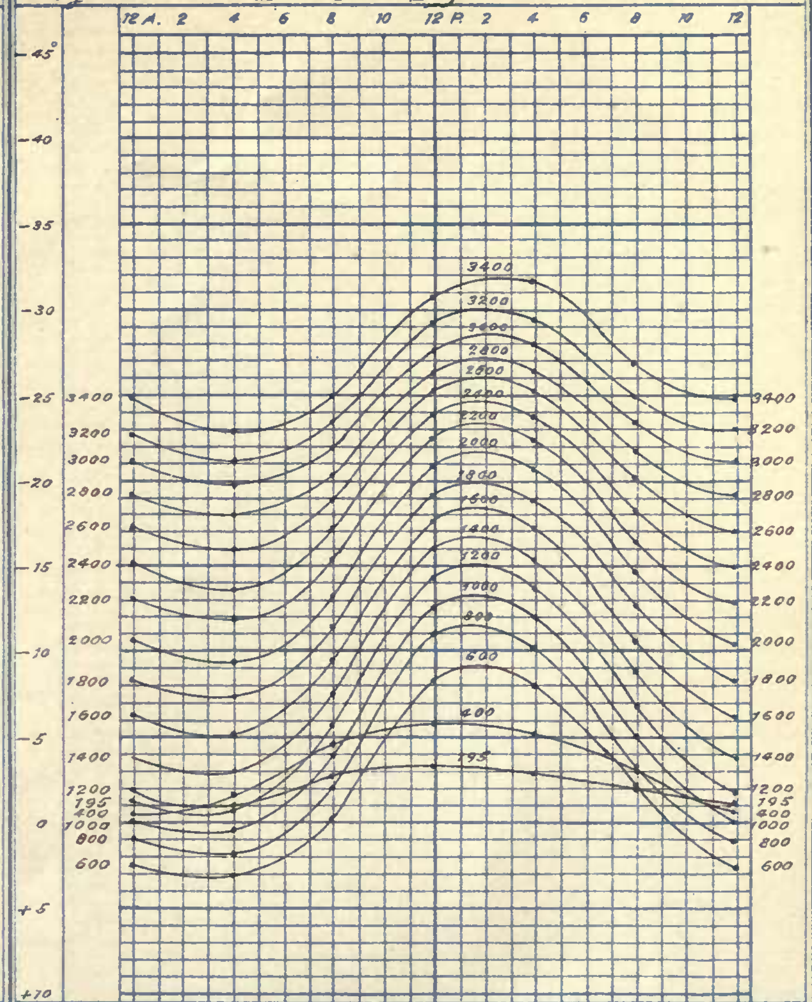


Fig. 4. March.

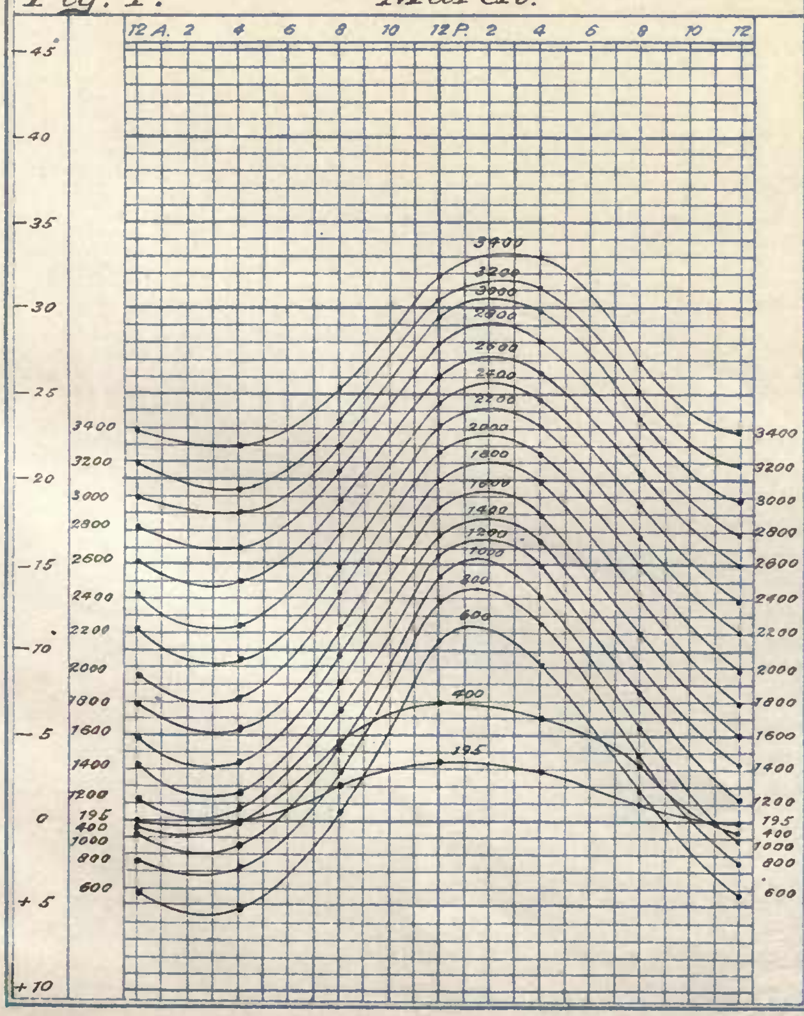


Fig. 5. April.

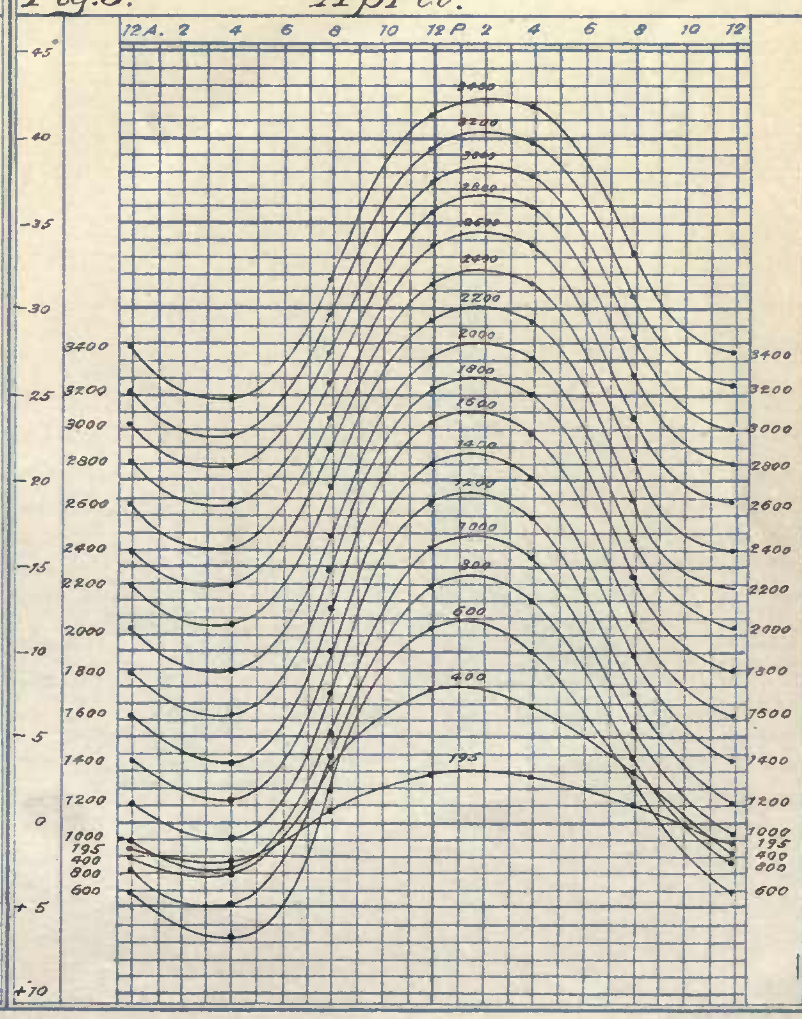


Fig. 6. May.

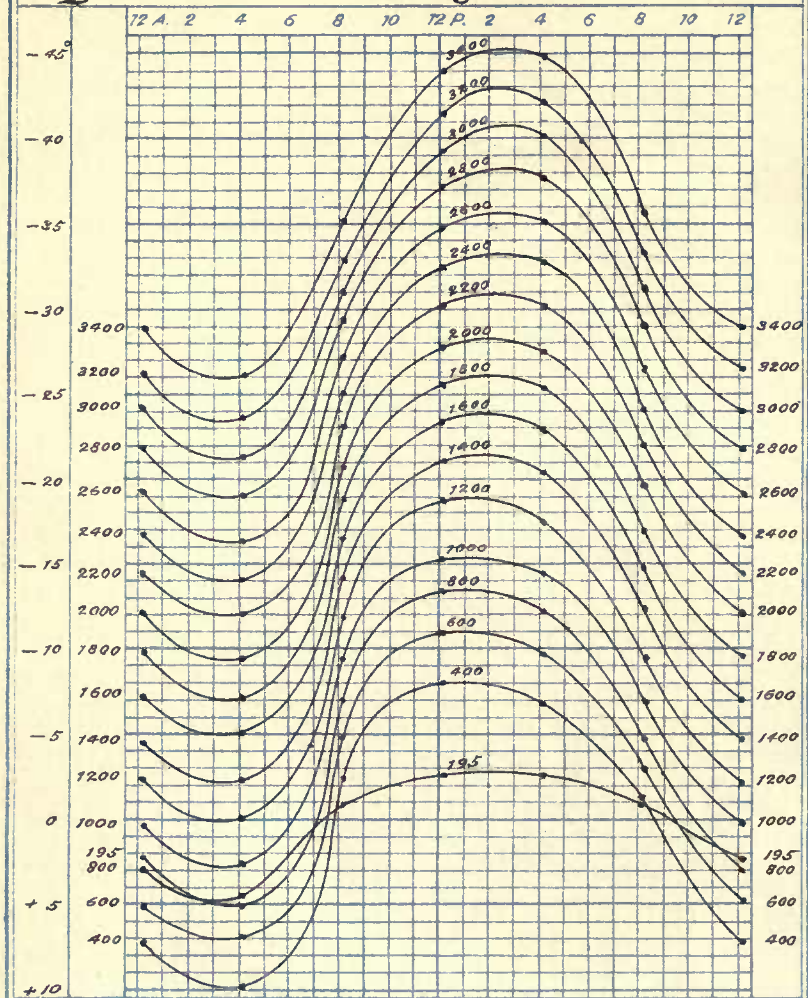


Fig. 7. June.

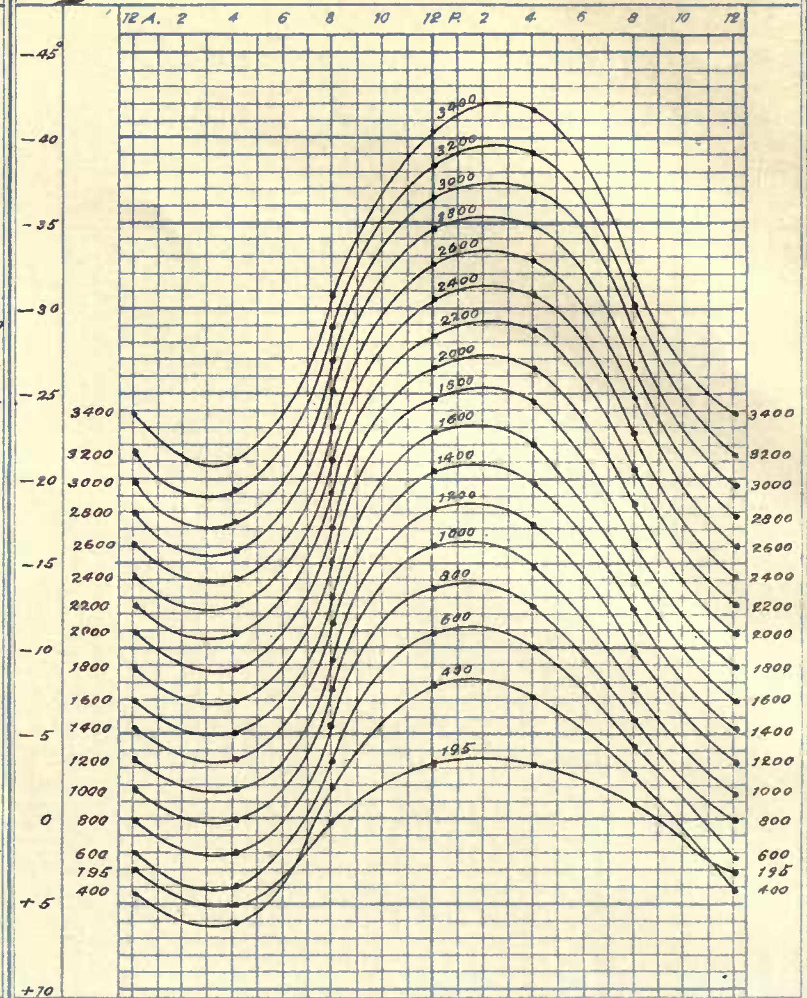


Fig. 8. July.

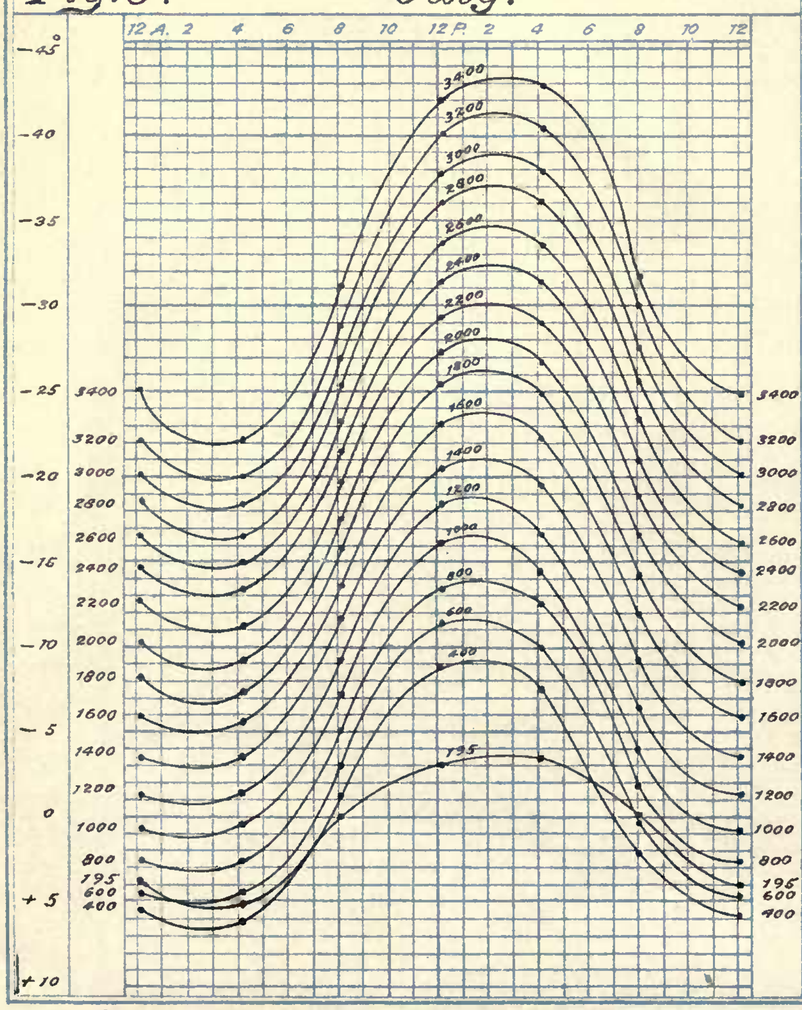


Fig. 9. August.

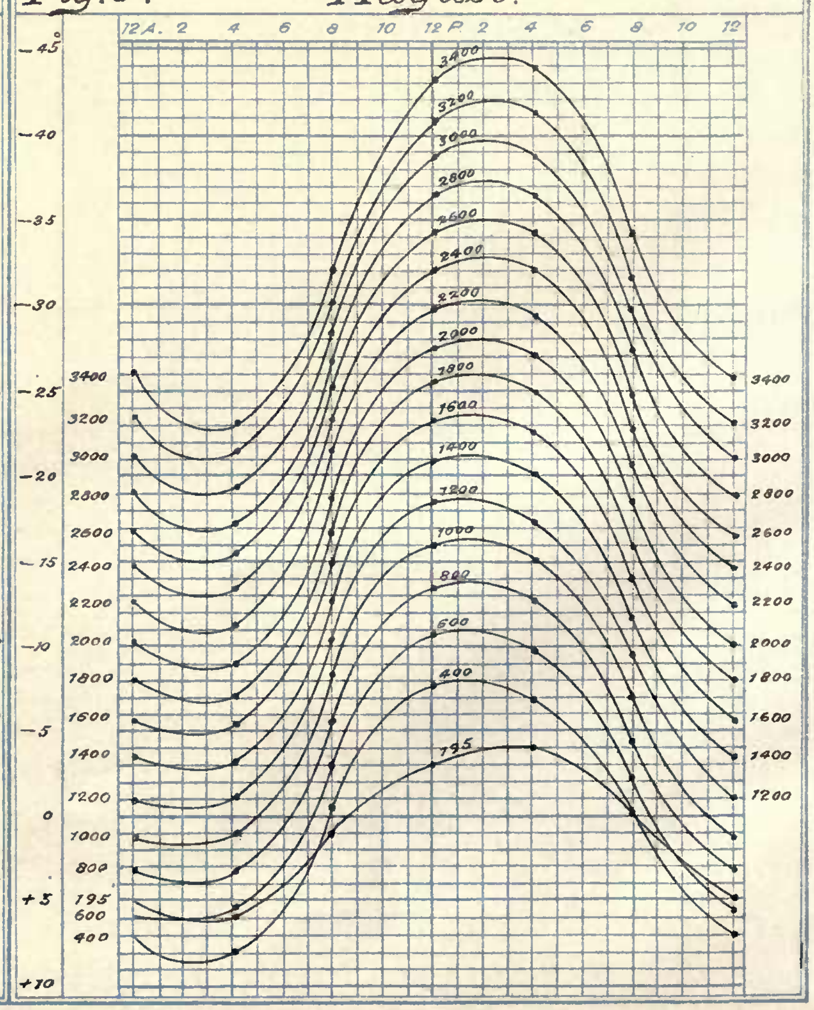


Chart XIV. Temperature-Falls in the Lower Strata.

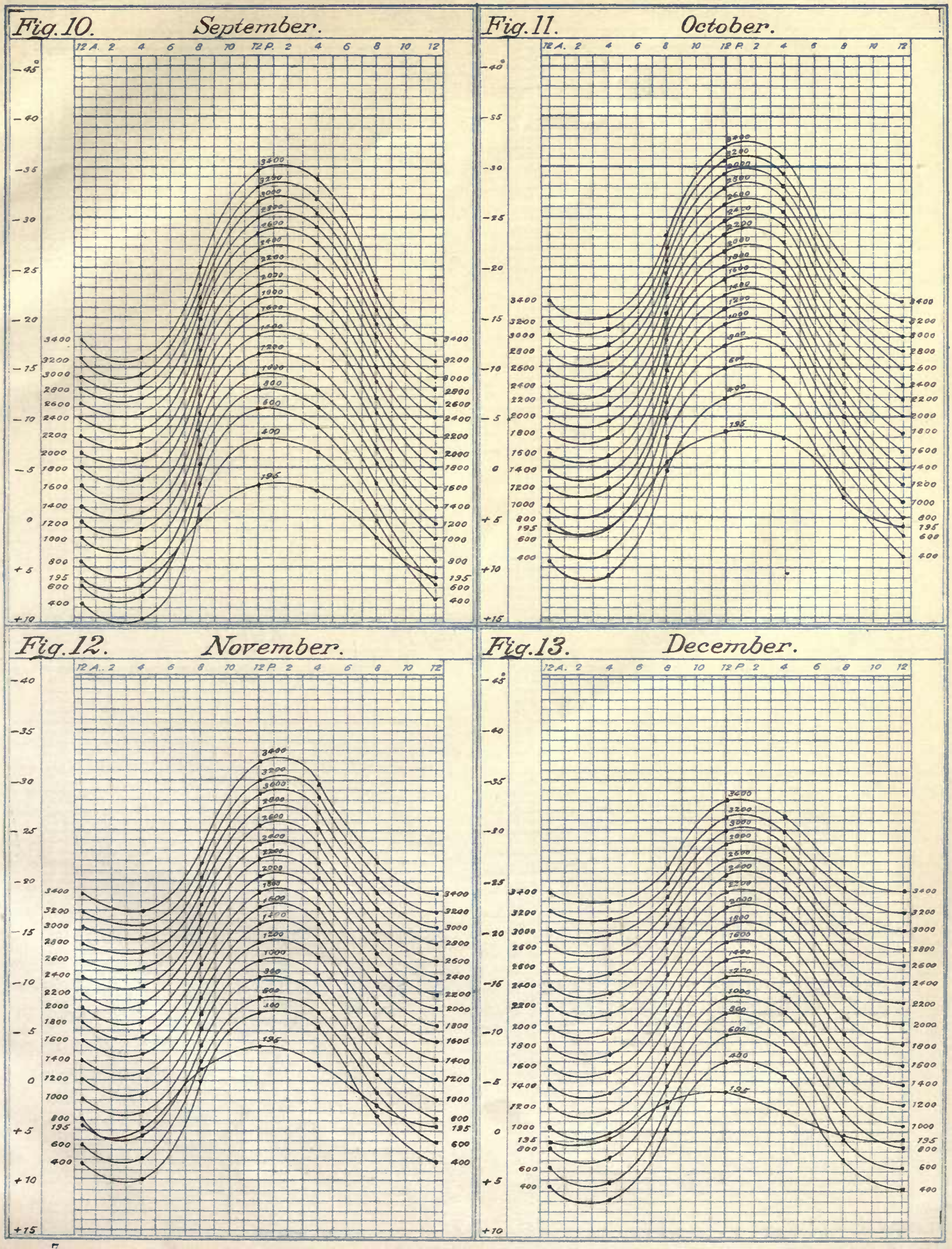


Fig. 14. January.

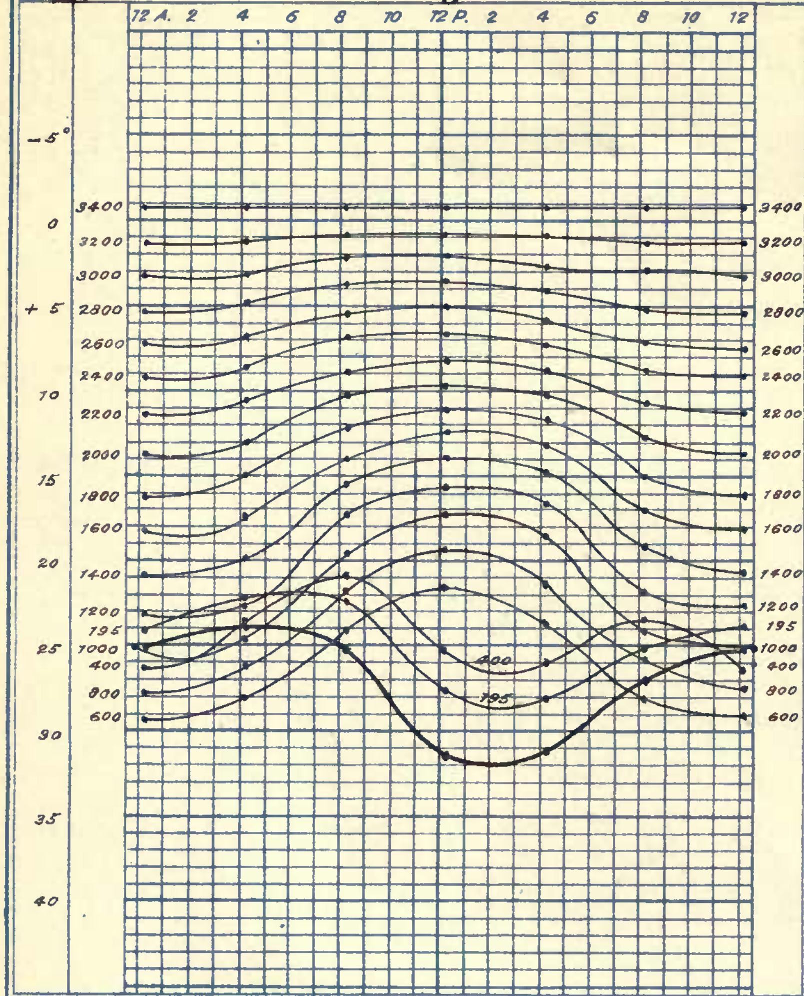


Fig. 15. February.

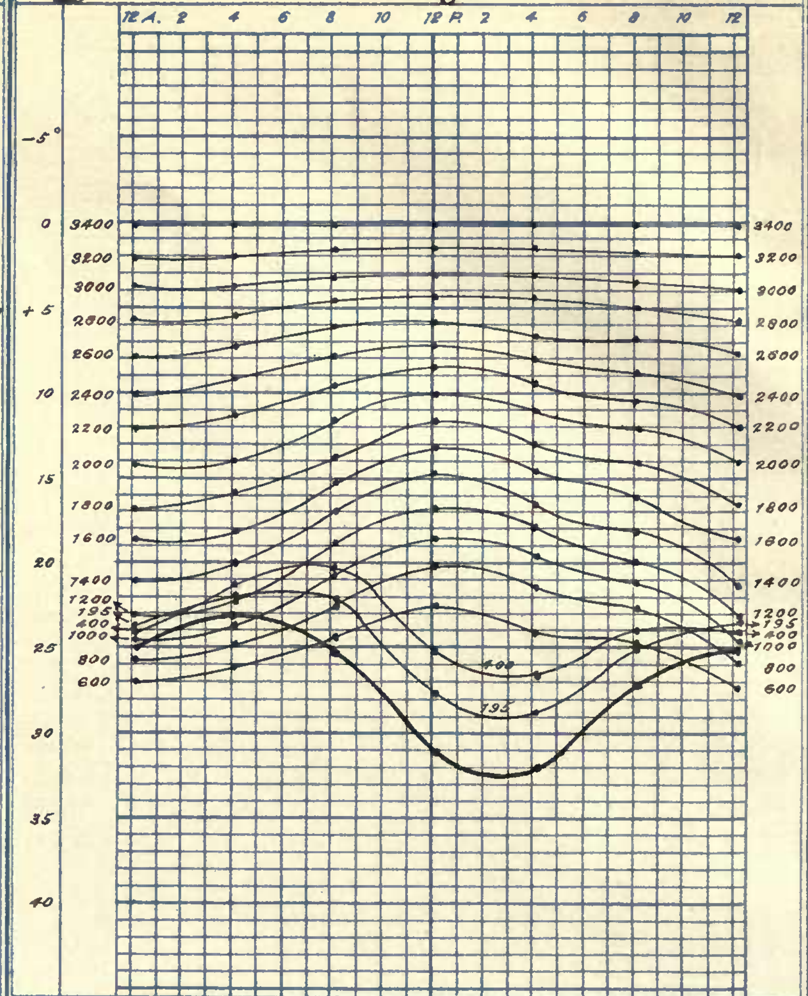


Fig. 16. March.

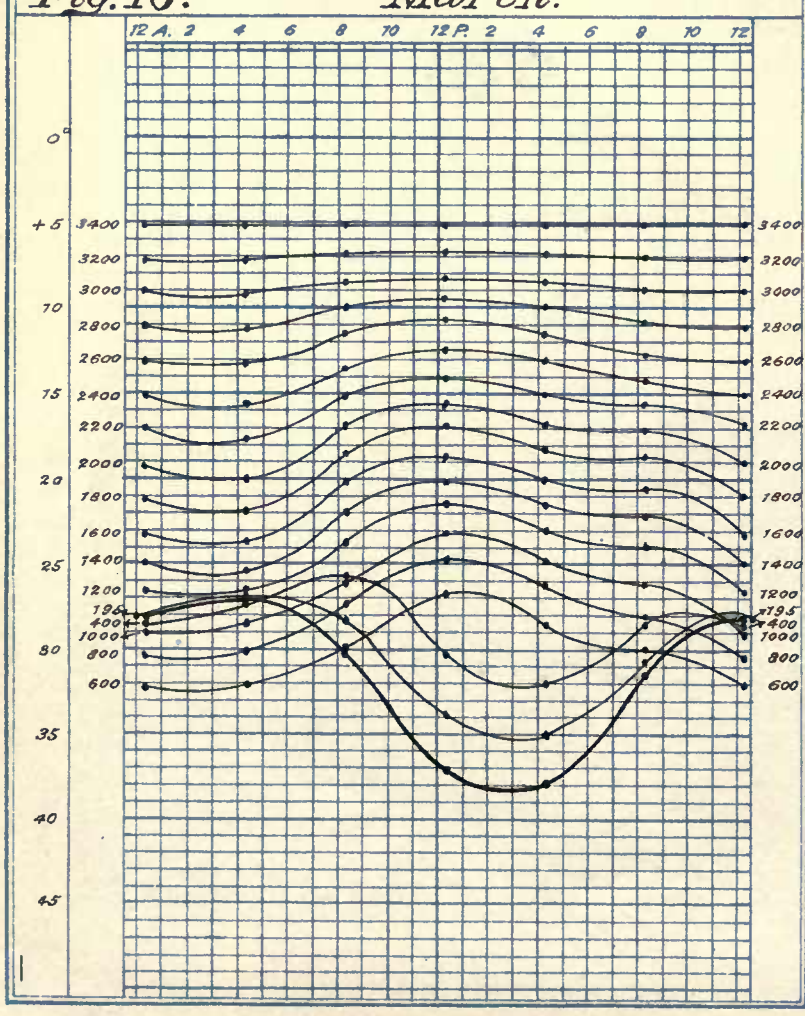


Fig. 17. April.

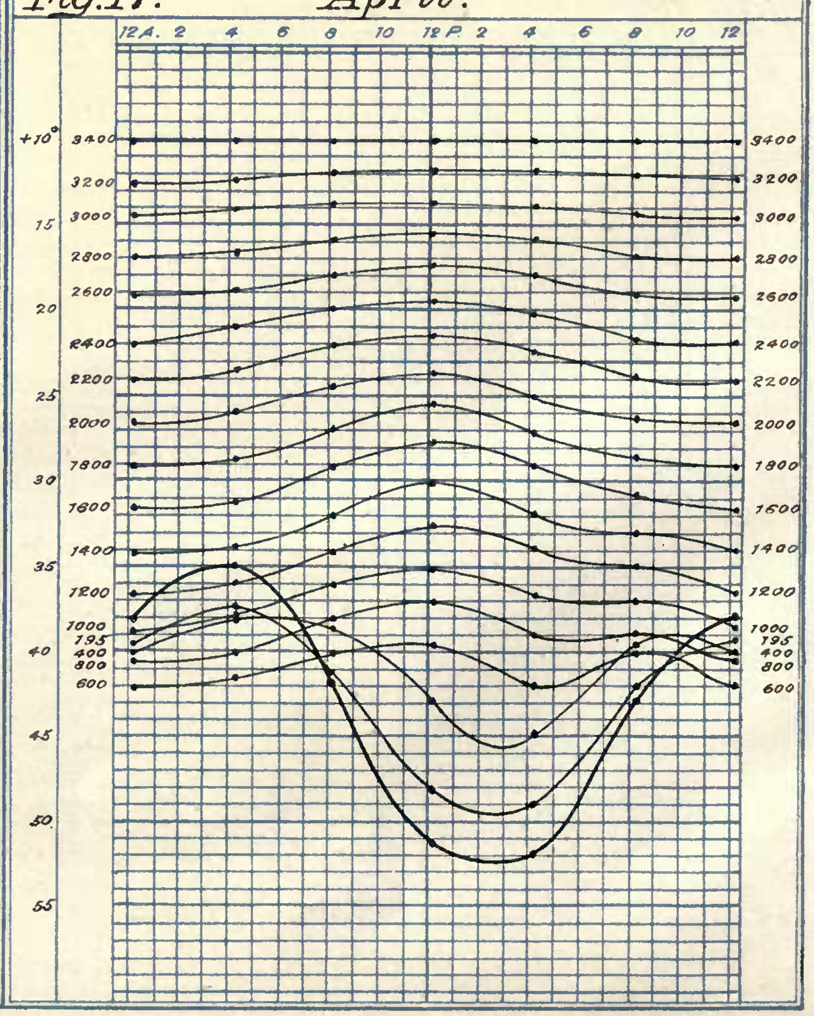


Fig. 18. May.

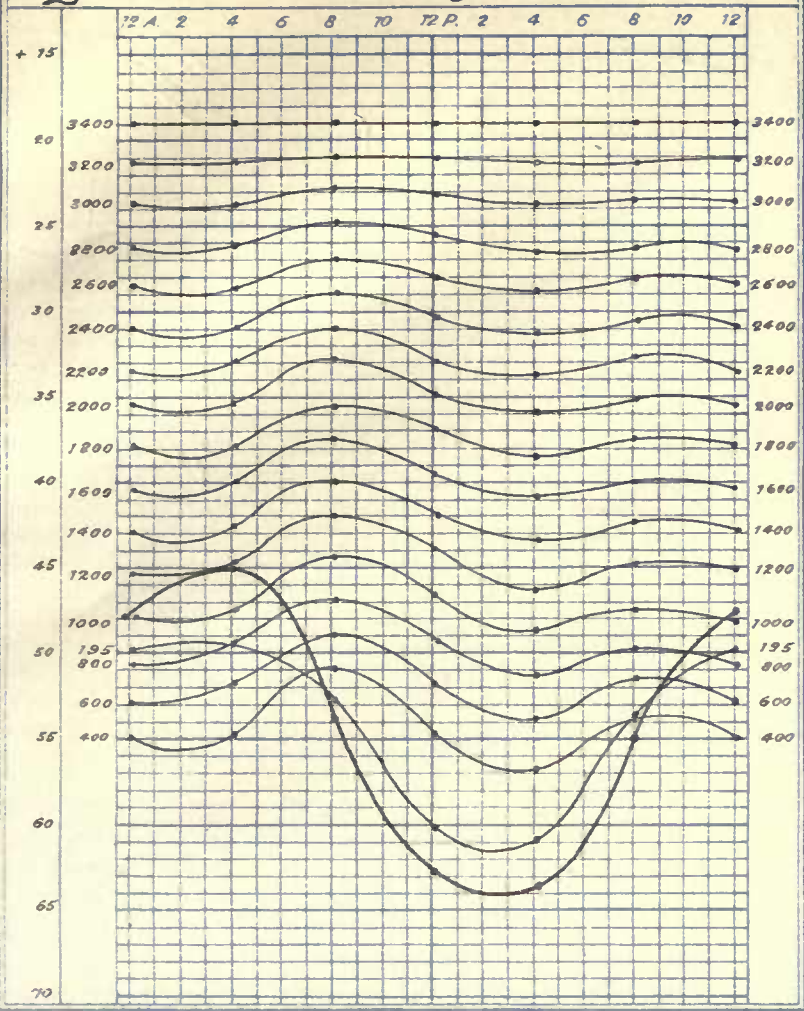


Fig. 19. June.

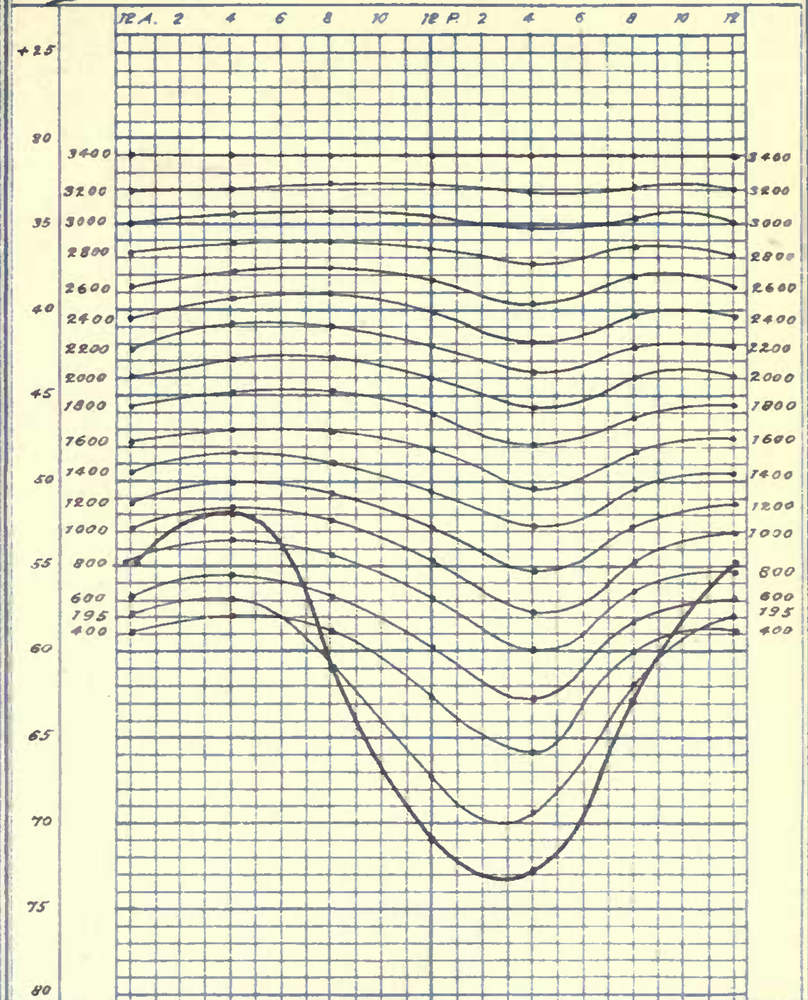


Fig. 20. July.

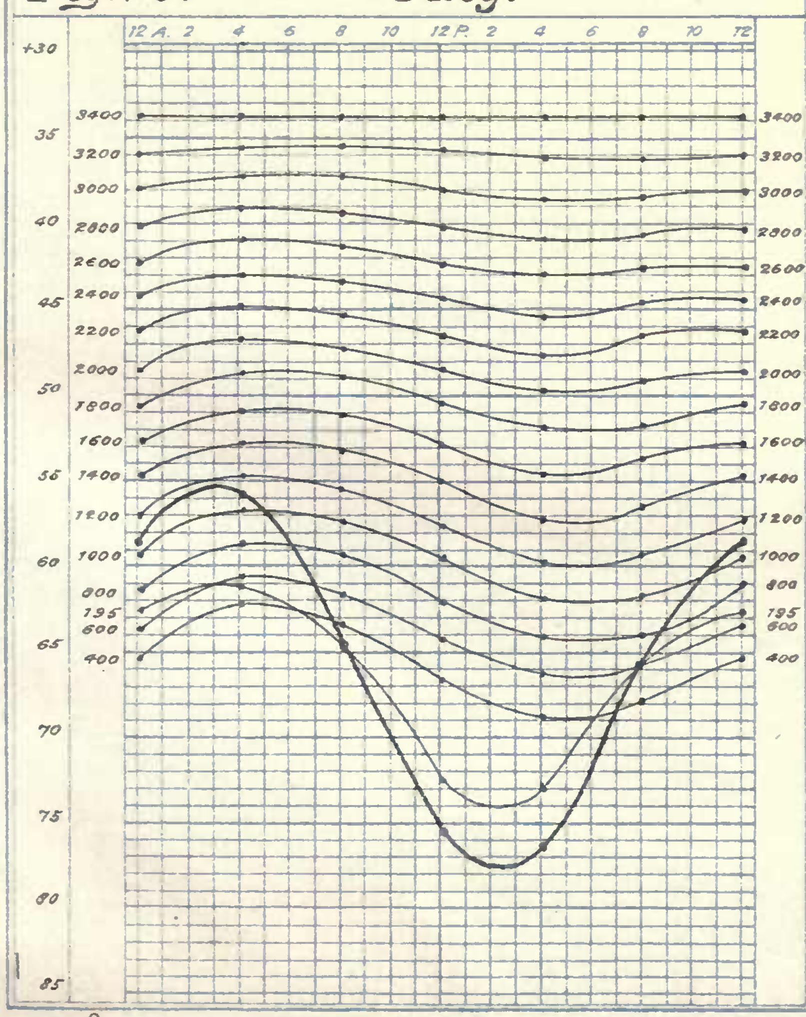


Fig. 21. August.

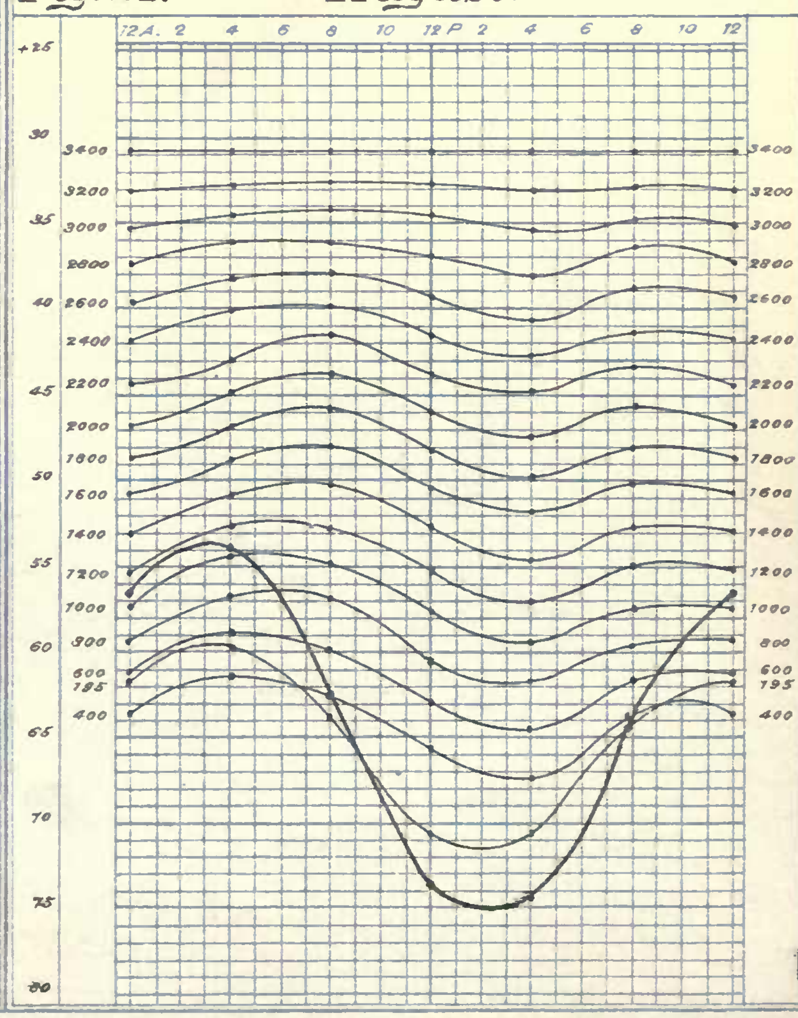


Fig. 22. September.

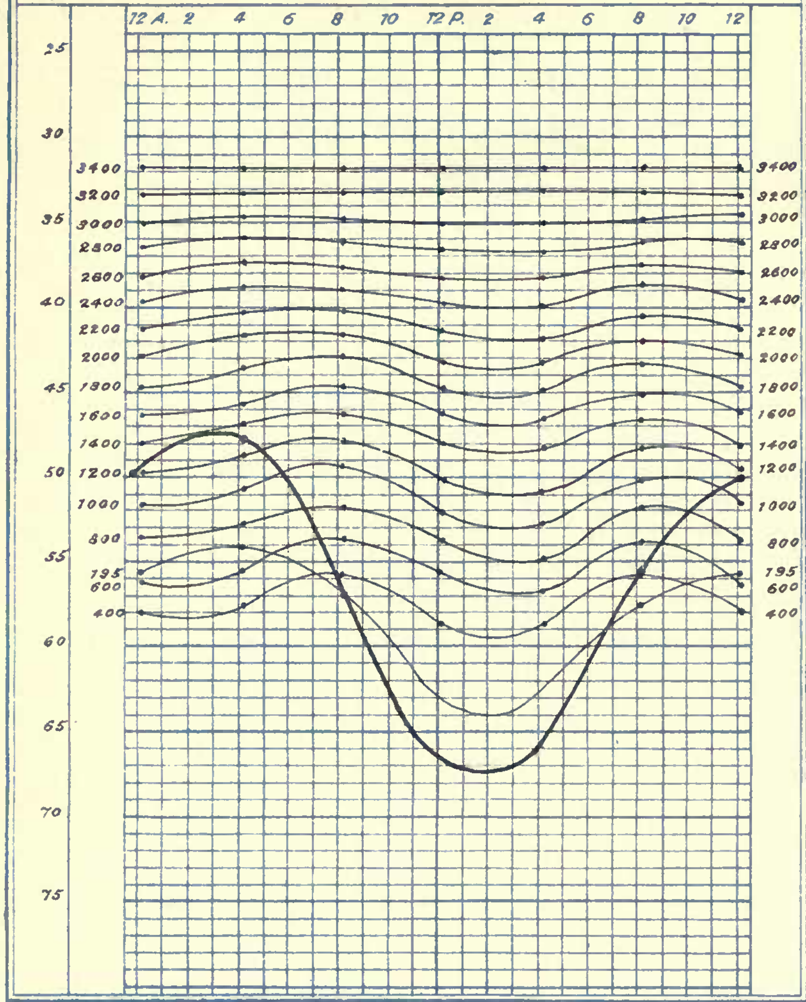


Fig. 23. October.

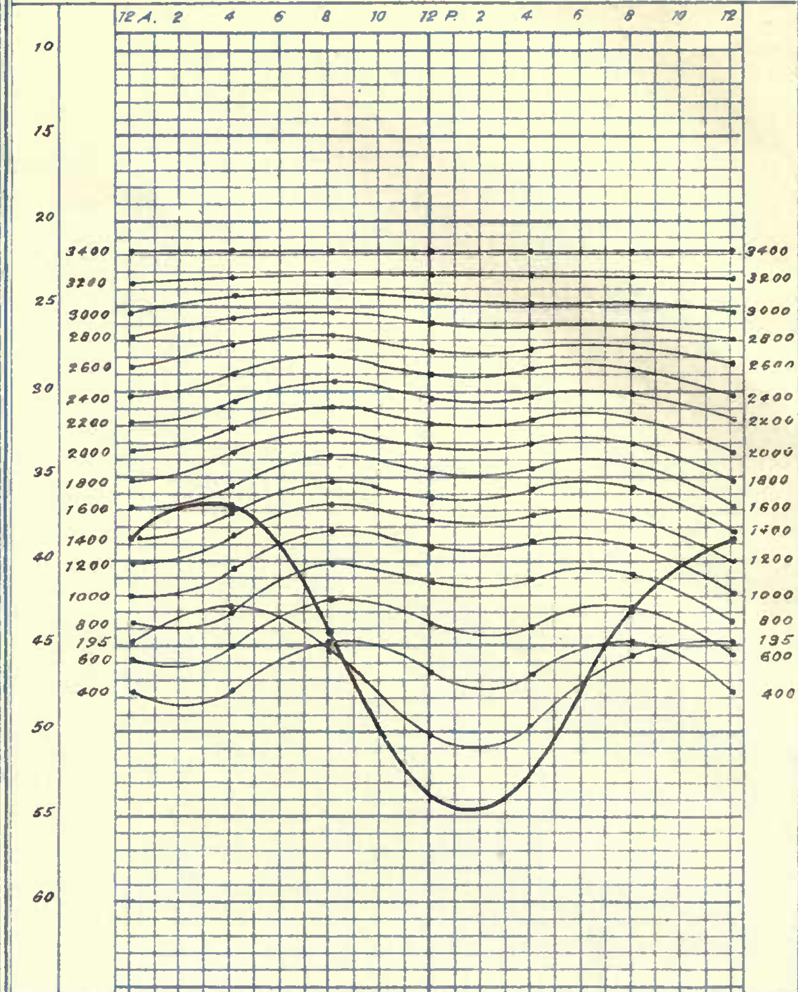


Fig. 24. November.

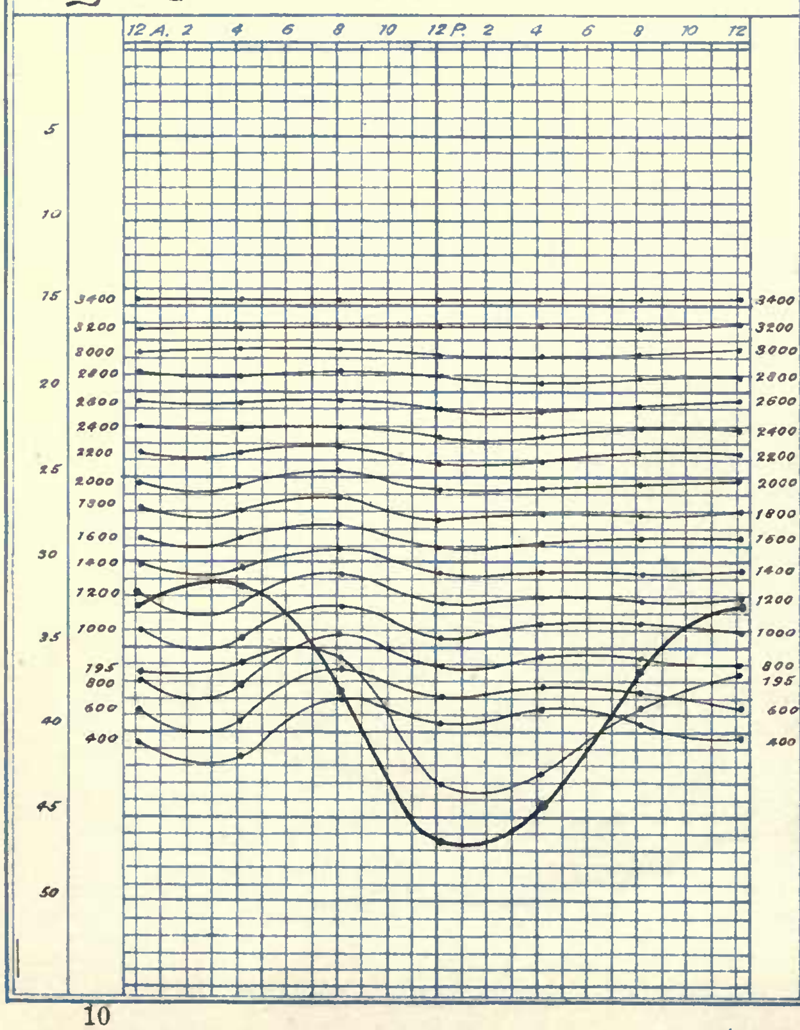
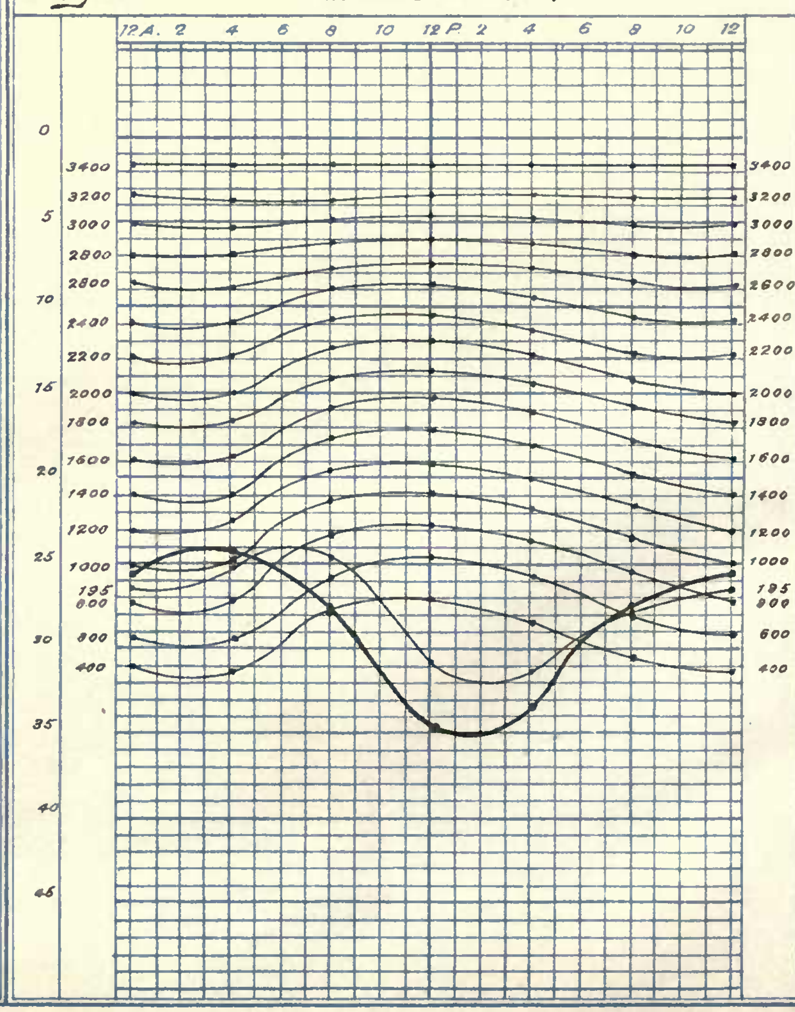


Fig. 25. December.



II.—THE DIURNAL PERIODS OF THE BAROMETRIC PRESSURE.

THE STATUS OF THE PROBLEM OF DIURNAL PRESSURE.

The physical relations between the waves of temperature and pressure in the lower strata of the atmosphere, together with their influence upon the electrical and the magnetical fields in the air, have formed subjects of constant investigation during the past forty years, but, unfortunately, without any satisfactory results. In my International Cloud Report, Weather Bureau, 1898, chapter 9, some account of the problem was given, and an attempt was made to throw some additional light upon the subject. The principal point brought out was the fact that there is a very close connection between the variation of the pressure and the magnetic fields over the earth, although I was unable to show what the physical process is which unites them. The papers of this series are supplementary to that investigation, and they show that two important elements have been lacking in the terms of the problem; namely, the variation of the temperature with the height, and the existence of streams of ions or free charges of electricity in the lower atmosphere. Without them it was not possible to explain the connection between the several types of observed phenomena.

There have been in general two lines of attack upon the problem of the coexistence of the single, the double, and the triple barometric waves, as determined by the harmonic components: First, that they are due directly to an effect of the temperature upon the pressure by a change in the density of the lower strata of air; and second, that a dynamic-forced wave is generated chiefly by solar radiation acting in the upper strata of the atmosphere. However, it has not been possible to associate the surface-temperature wave with the semidiurnal and the tridiurnal waves of pressure, because it has been assumed that the surface-temperature wave extends with the same periodic phase into the lower strata. We have shown in the preceding paper that this is not the case, and that there is now sufficient reason for reopening the problem at this place. Regarding the solution by a dynamic-forced wave, it has become more evident[1] from the studies of the absorption of the solar radiation, by means of the bolometer and the actinometer, that the solar energy can not build up temperature and dynamic waves in the upper strata, because the solar radiation is of such short wave lengths as to traverse the earth's atmosphere without general absorption. The outgoing radiation of much longer wave lengths from the earth's surface does, however, suffer absorption, so that such dynamic effects must belong to the lower, rather than to the higher, strata of the atmosphere. Further studies have been made by the Austrian meteorologists, Margules, Hann, and Trabert, in a series of interesting papers[2], since the year 1898.

It may be remarked that these discussions are confined to an account of the double period, apart from its natural combination with the single and triple periods. Suitable periodic variations of the coefficients, in latitude and longitude, were not to be found in the observations at the surface stations, nor at the mountain stations, and there was no data derived from the free air levels. Contact with the ground at low levels, or at high elevations, seems to have destroyed the actual temperature waves found in the free air at 400 meters and upward. It will, no doubt, now be possible to adapt these admirable mathematical studies of the Fourier series, as modified by the deflecting force of the earth's rotation and by friction, to the new temperature data pertaining to the strata up to 3000 meters elevation in the free air.

In order to place before the reader a brief summary of the facts of the barometric pressure waves which are to be explained, the following extract is quoted from my Cloud Report, pages 458, 459.

> Analyzing the observed barometric pressure by the harmonic series, $\Delta B = a_1 \sin (A_1 + x) + a_2 \sin (A_2 + 2x) + a_3 \sin (A_3 + 3x)$, and discussing the constants in respect to the observations, it is noted:
>
> 1. The normal value of the amplitude of the single daily oscillation a_1 is contained within the limits 0.00 and 0.50 mm. It is one-fourth to one-half the amount of a_2; its range is wide, being two or three times the normal value; it is very different at neighboring stations, and on the same parallel of latitude; it has greater amplitudes in mountain valleys, but smaller on the seacoast and in higher latitudes; it shows a reversal of phase in the polar regions, also above a certain neutral plane at a given elevation from the ground, produced by interference with the thermic wave; it has a yearly period, with maxima in June in higher latitudes, and in March and September on the equator.
>
> 2. The normal value of the phase A_1 is near 0°, where x is counted from midnight, and is the hour angle; it varies widely, from 277° to 55°; a_1 and A_1 must have a general and a local cause. The general cause varies with the latitude and also in the year; the local cause varies with the minor convection currents, and depends upon all the meteorological features which tend to produce local convection.
>
> 3. The amplitude of the double daily wave, a_2, is the principal term, and covers the limits 0.00 to 1.00 mm. of pressure. Its range is very narrow; it decreases regularly with the height proportionally to the pressure $\frac{B}{760}$; it is very constant over the entire earth up to latitude 55°; it varies with the latitude by a formula which requires an inversion of phase in the polar regions; it has a distinct variation with the year, but exhibits the following peculiarity, namely, that while the maximum insolation is in January at perihelion, the maximum of the semidiurnal wave is at the equinoxes in March and September; also the fact is remarkable that the sun in one hemisphere does not change the amplitude of the wave in the other hemisphere; it combines with the single "thermic" wave, but it is not controlled by it to any appreciable extent; it is smaller on seacoasts, islands, and on mountain tops, and is diminished a little by land and sea breezes; it is very large in mountain valleys.
>
> 4. The normal value of the phase of the double diurnal wave A_2 is 155°, corresponding to $9^h\ 50^m$ a. m.; its range is very small, 148° to 163°; it diminishes a little with the height, is retarded to 145° in higher latitudes, varies a little with the year, though in an opposite sense in the two hemispheres, and it is very independent of local meteorological influences.
>
> 5. The amplitude of the triple diurnal wave, a_3, is a very small quantity, being generally less than 0.10 mm. pressure. It diminishes a little with the latitude; its yearly period is very marked, and has maxima in winter and summer in both hemispheres, with minima at the equinoxes; its maximum is, however, in June, when the earth crosses the sun's equator, and not in July, when the heat is greatest in the Northern Hemisphere.
>
> 6. The phase of the triple daily period, A_3, has a normal value of 355°, with very small range, and with a small but very well marked yearly period.

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[1] See Monthly Weather Review, December 1902, figs. 3 and 4.

[2] Ueber die tägliche Drehung der mittleren Windrichtung und über eine Oscillation der Luftmassen von halbtägiger Periode auf Berggipfeln von 2 bis 4 km. Seehöhe. J. Hann. Wien. 1902.

Same in Meteorologische Zeitschrift. Oktober, November, 1903.

Die Theorie der täglichen Luftdruckschwankung von Margules und die tägliche Oscillation der Luftmassen. W. Trabert. Met. Zeit. November, December, 1903.

THE DIURNAL, SEMIDIURNAL, AND TRIDIURNAL PRESSURE WAVES COMPUTED FROM THE SURFACE OBSERVATIONS.

We can obtain the three component pressure waves from the Weather Bureau observations by employing the data contained in Mr. P. C. Day's paper, prepared by direction of Brig. Gen. A. W. Greely, "Diurnal Fluctuations of Atmospheric Pressure at twenty-nine selected stations in the United States, Washington, 1891." The tables give the local hourly corrections to the daily mean pressure; hence by changing the signs, we obtain ΔB, the variations of the pressure for each hour, which are to be resolved into three harmonic components by the Fourier series. Five stations were selected which are naturally comparable with Blue Hill, being located at short distances above sea level, Boston, New York, Washington, Buffalo, and Cleveland. The mean variation at each hour was computed for these stations, and it appears in the column of the Table 1 marked ΔB, for each month of the year. In order that it might be learned whether the continental plateau stations produce the same results, the following stations, Bismarck, St. Louis, Dodge, Denver, and Salt Lake City, were computed in the same manner throughout the year. Since no

TABLE 1.—*Diurnal, semidiurnal, and tridiurnal pressure waves observed at the surface. Unit = 0.001 inch mercury.*

Hours.	January.				February.				March.				April.			
	ΔB.	I.	II.	III.	ΔB.	I.	II.	III.	ΔB.	I.	II.	III.	ΔB.	I.	II.	III.
12a	0	-1	+1	0	+1	-1	+3	-1	+3	-1	+4	0	+4	-1	+5	0
1	-3	+2	-9	+4	-2	+2	-7	+3	0	+4	-5	+1	0	+3	-3	0
2	-5	+4	-15	+6	-5	+3	-14	+6	-3	+6	-12	+3	-4	+7	-11	0
3	-6	+4	-15	+5	-7	+5	-17	+5	-4	+10	-16	+2	-5	+12	-16	-1
4	-6	+7	-13	0	-7	+8	-16	+1	-3	+13	-16	0	-2	+15	-16	-1
5	-4	+10	-9	-5	-4	+10	-11	-3	+6	+16	-10	0	+4	+16	-12	0
6	+1	+11	-3	-7	+2	+11	-4	-5	+8	+15	-5	-2	+12	+17	-5	0
7	+10	+9	+5	-4	+10	+13	+4	-7	+16	+14	+4	-2	+20	+17	+3	0
8	+20	+8	+12	0	+20	+9	+12	-1	+24	+12	+12	0	+26	+15	+11	0
9	+28	+7	+17	+4	+29	+9	+17	+3	+29	+11	+17	+1	+29	+13	+16	0
10	+31	+7	+18	+6	+32	+7	+19	+6	+29	+8	+18	+3	+27	+10	+17	0
11	+24	+5	+14	+5	+23	+4	+14	+5	+19	+5	+12	+2	+17	+6	+12	-1
12p	+2	+1	+1	0	+5	+1	+3	+1	+4	0	+4	0	+5	+1	+5	-1
1	-15	-1	-9	-5	-11	-1	-7	-3	-9	-4	-5	0	-6	-3	-3	0
2	-25	-3	-15	-7	-22	-3	-14	-5	-20	-6	-12	-2	-17	-6	-11	0
3	-24	-5	-15	-4	-27	-3	-17	-7	-27	-9	-16	-2	-26	-10	-16	0
4	-20	-7	-13	0	-25	-8	-16	-1	-28	-12	-16	0	-30	-14	-16	0
5	-14	-9	-9	+4	-18	-10	-11	+3	-25	-16	-10	+1	-28	-16	-12	0
6	-7	-10	-3	+6	-9	-11	-4	+6	-17	-15	-5	+3	-22	-17	-5	0
7	0	-11	+5	+5	-2	-12	+4	+5	-9	-15	+4	+2	-14	-16	+3	-1
8	+4	-8	+12	0	+4	-9	+11	+1	-1	-13	+12	0	-5	-15	+11	-1
9	+5	-7	+17	-5	+5	-9	+17	-3	+4	-13	+17	0	+2	-14	+16	0
10	+4	-7	+18	-7	+5	-9	+14	-5	+6	-10	+18	-2	+6	-11	+17	0
11	+3	-7	+14	-4	+4	-3	+14	-7	+5	-5	+12	-2	+6	-6	+12	0
12	0	-1	+1	0	+1	-1	+3	-1	+3	-1	+4	0	+4	-1	+5	0

Hours.	May.				June.				July.				August.			
12a	-1	-5	+4	0	-0	-7	+6	+1	0	-6	+6	0	-1	-6	+5	0
1	-4	-1	-3	0	-4	-3	-1	0	-2	-2	0	0	-3	-1	-2	0
2	-7	+3	-9	-1	-7	+2	-7	-2	-5	+2	-6	-1	-6	+3	-8	-1
3	-8	+8	-14	-2	-8	+6	-22	-2	-5	+7	-11	-1	-6	+6	-11	-1
4	-4	+12	-15	-1	-5	+11	-14	-2	-2	+11	-13	0	-3	+12	-14	-1
5	+4	+15	-11	0	+3	+13	-11	+1	+3	+14	-12	+1	+4	+15	-11	0
6	+11	+17	-6	0	+13	+17	-6	+2	+11	+15	-7	+3	+14	+17	-5	+2
7	+22	+18	+3	+1	+20	+17	+1	+2	+19	+16	+1	+2	+20	+18	+1	+1
8	+27	+17	+10	0	+26	+17	+8	+1	+24	+17	+7	0	+26	+18	+8	0
9	+29	+15	+14	0	+29	+16	+13	0	+27	+15	+12	0	+28	+15	+13	0
10	+27	+14	+14	-1	+27	+15	+12	-2	+25	+10	+16	-1	+26	+11	+16	-1
11	+19	+11	+10	-2	+20	+11	+11	-2	+19	+9	+11	-1	+20	+10	+11	-1
12p	+9	+6	+4	-1	+11	+7	+6	-2	+11	+5	+6	0	+11	+7	+5	-1
1	-1	+2	-3	0	+2	+2	-1	+1	+2	+1	0	+1	-1	+1	-2	0
2	-11	-2	-9	0	-7	-2	-7	+2	-7	-2	-6	+3	-9	-3	-8	+2
3	-20	-7	-14	+1	-16	-6	+12	+2	-16	-7	-11	+2	-16	-6	-11	+1
4	-25	-10	-15	0	-22	-9	-14	+1	-23	-10	-13	0	-24	-10	-14	0
5	-26	-15	-11	0	-25	-14	-11	0	-26	-14	-12	0	-26	-15	-11	0
6	-22	-15	-6	-1	-25	-17	-6	-2	-24	-16	-7	-1	-24	-20	-5	-1
7	-17	-18	+3	-2	-19	-18	+1	-2	-18	-18	+1	-1	-18	-18	+1	-1
8	-8	-17	+10	-1	-11	-17	+8	-2	-10	-17	+7	0	-10	-17	+8	-1
9	-2	-16	+14	0	-3	-17	+13	+1	-3	-16	+12	+1	-3	-16	+13	0
10	+1	-13	+14	0	+1	-15	+14	+2	+6	-13	+16	+3	+1	-17	+16	+2
11	+1	-10	+10	+1	+2	-11	+11	+2	+2	-11	+11	+2	+1	-11	+11	+1
12	-1	-5	+4	0	0	-7	+6	+1	0	-6	+6	0	-1	-6	+5	0

Hours.	September.				October.				November.				December.			
12a	0	-4	+5	-1	0	-3	+3	0	0	0	-1	+1	0	0	-1	+1
1	-2	0	-3	0	-3	+2	-7	+2	-2	+3	-9	+4	-2	+3	-10	+5
2	-5	+4	-10	+1	-5	+6	-13	+2	-5	+4	-14	+5	-4	+3	-14	+7
3	-6	+8	-15	+1	-5	+10	-16	+1	-5	+7	-15	+3	-5	+6	-15	+4
4	-3	+14	-17	0	-2	+13	-15	0	-4	+9	-13	0	-5	+9	-12	-2
5	+4	+15	-11	0	+4	+16	-10	-2	0	+12	-8	-4	-2	+10	-7	-5
6	+13	+17	-4	0	+12	+17	-3	-2	+7	+15	-2	-6	+4	+11	-1	-6
7	+21	+17	+4	0	+21	+17	+6	-2	+15	+11	+6	-2	+12	+9	+6	-3
8	+27	+18	+10	-1	+28	+16	+12	9	+24	+11	+12	+1	+21	+9	+11	+1
9	+30	+16	+14	0	+31	+13	+16	+2	+30	+9	+17	+4	+29	+8	+16	+5
10	+28	+12	+15	+1	+29	+11	+16	+2	+29	+7	+17	+5	+30	+6	+17	+7
11	+21	+8	+12	+1	+19	+8	+10	+1	+16	+3	+10	+3	+17	+3	+10	+4
12p	+10	+5	+5	0	+6	+3	+3	0	-2	-1	-1	0	-2	+1	-1	-2
1	-2	+1	-3	0	-10	-1	-7	-2	-15	-2	-9	-4	-17	-2	-10	-5
2	-14	-4	-10	0	-21	-6	-13	-2	-23	-3	-14	-6	-24	-4	-14	-6
3	-24	-9	-15	0	-27	-9	-16	-2	-25	-8	-15	-2	-24	-6	-15	-3
4	-31	-13	-17	-1	-28	-13	-15	0	-22	-10	-13	+1	-18	-7	-12	+1
5	-26	-15	-11	0	-23	-15	-10	+2	-16	-12	-8	+4	-11	-9	-7	+5
6	-21	-18	-4	+1	-17	-16	-3	+2	-10	-12	-2	+5	-5	-11	-1	+7
7	-13	-18	+4	+1	-10	-17	+6	+1	-3	-12	+6	+3	-1	-11	+6	+4
8	-8	-18	+10	0	-4	-15	+12	0	-1	-13	+12	0	+1	-8	+11	-2
9	-2	-16	+14	0	0	-14	+16	-2	+3	-10	+17	-4	+1	-8	+16	-5
10	+1	-14	+15	0	+2	-12	+16	-2	+4	-7	+17	-6	+3	-5	+17	-6
11	+2	-10	+12	0	+1	-7	+10	-2	+3	-5	+10	-2	+3	-8	+10	-3
12	0	-4	+5	-1	0	-3	+3	0	0	0	-1	+1	0	0	-1	+1

TABLE 2.—*Diurnal, semidiurnal, and tridiurnal temperature waves, on three planes. Unit = 1 degree Fahrenheit.*

JANUARY.

Hours.	195 meters.				400 meters.				1000 meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12a.....	+0.7	+1.7	-1.0	-0.0	-1.8	-0.5	-1.3	0.0	-3.4	-4.8	+0.6	+0.8	-3.6	-1.7	+0.8
1......	+1.5	+2.2	-0.9	+0.2	-2.0	+0.1	-1.9	-0.2	-3.9	-4.7	+0.4	+0.4	-2.4	-2.4	+0.4
2......	+2.0	+2.7	-0.8	+0.1	-1.9	+0.4	-2.1	-0.2	-4.1	-4.3	-0.2	0.0	-1.2	-2.7	-0.1
3......	+2.5	+3.0	-0.5	0.0	-1.3	-0.6	-1.8	-0.1	-3.8	-3.7	+0.1	-0.2	-0.1	-2.2	-0.3
4......	+2.7	+3.1	-0.3	-0.1	+0.2	+1.4	-0.9	-0.3	-3.1	-3.2	+0.3	-0.2	+1.3	-0.9	-0.6
5......	+2.9	+2.9	+0.1	-0.1	+1.9	+1.4	+0.4	+0.1	-1.9	-2.1	+0.2	0.0	+2.2	+0.7	0.0
6......	+2.9	+2.5	+0.4	0.0	+3.0	+1.5	+1.3	+0.2	-0.6	-0.3	-0.1	+0.2	+3.7	+1.6	+0.4
7......	+2.8	+2.0	+0.8	0.0	+3.5	+1.5	+1.9	+0.1	+0.8	+0.4	-0.1	+0.5	+3.9	+2.6	+0.6
8.....	+2.7	+1.5	+1.2	0.0	+3.6	+1.4	+2.2	0.0	+2.1	+1.3	0.0	+0.8	+4.2	+3.4	+0.8
9.....	+1.8	+0.1	+1.5	+0.2	+3.2	+1.3	+2.1	-0.2	+3.0	+2.5	+0.1	+0.4	+3.9	+3.7	+0.4
10.....	+0.4	-0.2	+0.5	+0.1	+2.2	+1.1	+1.3	-0.2	+3.6	+3.2	+0.4	0.0	+4.1	+2.2	-0.1
11p.....	-1.3	-1.0	-0.3	0.0	+1.0	+0.9	+0.2	-0.1	+4.1	+3.9	+0.4	-0.2	+3.3	+0.3	-0.3
12......	-2.7	-1.6	-1.0	-0.1	-0.8	-0.2	-1.3	-0.3	+4.5	+4.1	+0.6	-0.2	+2.3	-1.7	-0.6
1......	-3.3	-2.3	-0.9	-0.1	-1.8	0.0	-1.9	+0.1	+4.6	+4.2	+0.4	0.0	+1.9	-2.4	0.0
2	-3.5	-2.7	-0.8	0.0	-2.2	-0.3	-2.1	+0.2	+4.4	+4.0	+0.2	+0.2	+1.0	-2.7	+0.4
3......	-3.5	-3.0	-0.5	0.0	-2.3	-0.6	-1.8	+0.1	+4.0	+3.4	+0.1	+0.5	-0.3	-2.2	+0.6
4......	-3.3	-3.0	-0.3	0.0	-1.9	-1.0	-0.6	0.0	+3.6	+2.5	+0.3	+0.8	-1.5	-0.9	+0.8
5......	-2.8	-3.1	+0.1	+0.2	-1.1	-1.3	+0.4	-0.2	+2.2	+1.6	+0.2	+0.4	-2.8	+0.7	+0.4
6......	-2.2	-2.7	+0.4	+0.1	-0.4	-1.5	+1.3	-0.2	+0.4	+0.5	-0.1	0.0	-3.7	+1.6	-0.1
7......	-1.3	-2.1	+0.8	0.0	+0.3	-1.5	+1.9	-0.1	-1.0	-0.7	-0.1	-0.2	-4.3	+2.6	-0.3
8......	-0.3	-1.4	+1.2	-0.1	+0.8	-1.1	+2.2	-0.3	-2.1	-1.9	0.0	-0.2	-4.4	+3.4	-0.6
9......	+0.1	-1.3	+1.5	-0.1	+0.9	-1.3	+2.1	+0.1	-2.8	-2.9	+0.1	0.0	-5.4	+3.7	0.0
10......	+0.5	0.0	+0.5	0.0	+0.4	-1.1	+1.3	+0.2	-3.2	-3.8	+0.4	+0.2	-4.9	+2.2	+0.4
11....	+0.7	+1.0	-0.3	0.0	-0.6	-0.9	+0.2	+0.1	-3.4	-4.3	+0.4	+0.5	-4.2	+0.3	+0.6
12......	+0.7	+1.7	-1.0	0.0	-1.8	-0.5	-1.3	0.0	-3.4	-4.8	+0.6	+0.8	-3.6	-1.7	+0.8
	24.7				24.2				21.6						

FEBRUARY.

Hours.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a....	+1.2	+2.0	-0.7	-0.1	-0.8	+0.6	-1.2	-0.2	-3.2	-2.8	-0.1	-0.3	-0.2	-2.0	-0.6
1......	+1.7	+2.6	-1.0	+0.1	+0.1	+1.1	-1.2	+0.2	-2.9	-3.0	+0.2	-0.1	-0.3	-2.0	+0.2
2......	+2.2	+3.1	-1.1	+0.2	+1.0	+1.4	-1.0	+0.6	-2.7	-3.1	+0.1	+0.3	+1.4	-2.0	+1.1
3......	+2.6	+3.4	-1.0	+0.2	+1.7	+0.9	-0.7	+0.5	-2.4	-2.7	-0.1	+0.4	+1.6	-1.8	+1.1
4......	+2.7	+3.5	-0.8	0.0	+2.3	+1.8	-0.5	0.0	-2.1	-2.3	-0.2	+0.4	+3.5	-1.5	+0.4
5......	+3.0	+3.3	-0.2	-0.1	+2.7	+2.8	-0.1	0.0	-1.6	-1.8	-0.2	+0.4	+4.3	-0.5	+0.3
6......	+3.1	+2.8	+0.5	-0.2	+3.1	+2.7	+0.5	-0.1	-1.0	-1.3	+0.2	+0.1	+4.2	+1.2	-0.2
7......	+2.9	+2.3	+0.9	-0.3	+3.3	+2.3	+1.1	-0.1	-0.3	-0.4	+0.3	-0.2	+4.2	+2.3	-0.6
8......	+2.7	+2.1	+0.7	-0.1	+3.5	+2.2	+1.5	-0.2	+0.5	+0.4	+0.4	-0.3	+4.7	+2.6	-0.6
9......	+1.8	+0.7	+1.0	+0.1	+3.3	+1.5	+1.6	+0.2	+1.3	+0.9	+0.5	-0.1	+3.1	+3.1	+0.2
10......	+0.7	-0.1	+0.6	+0.2	+2.3	+0.7	+1.0	+0.6	+2.2	+1.5	+0.4	+0.3	+2.1	+2.0	+1.1
11......	-0.7	-0.9	0.0	+0.2	+0.4	0.0	-0.1	+0.5	+2.7	+2.2	+0.1	+0.4	+1.3	0.0	+1.1
12 p....	-2.5	-1.8	-0.7	0.0	-1.6	-0.4	-1.2	0.0	+3.1	+2.8	-0.1	+0.4	+0.6	-2.0	+0.4
1......	-3.6	-2.5	-1.0	-0.1	-2.4	-1.2	-1.2	0.0	+3.2	+2.6	+0.2	+0.4	-1.1	-2.0	+0.3
2......	-4.3	-3.0	-1.1	-0.2	-3.0	-1.9	-1.0	-0.1	+2.8	+2.6	+0.1	+0.1	-2.3	-2.0	-0.2
3......	-4.5	-3.2	-1.0	-0.3	-3.1	-2.3	-0.7	-0.1	+2.3	+2.6	+0.1	-0.2	-2.9	-1.8	-0.6
4......	-4.3	-3.4	-0.8	-0.1	-3.2	-2.5	-0.5	-0.2	+1.7	+2.2	-0.2	-0.3	-3.7	-1.5	-0.6
5......	-3.3	-3.2	-0.2	+0.1	-2.8	-2.9	-0.1	+0.2	+1.3	+1.6	+0.2	+0.1	-4.5	-0.5	+0.2
6......	-2.2	-2.9	+0.5	+0.2	-2.1	-3.2	+0.5	+0.6	+1.3	+0.8	+0.2	+0.3	-5.3	+1.2	+1.1
7......	-1.2	-2.3	+0.9	+0.2	-1.2	-2.8	+1.1	+0.5	+0.8	+0.1	+0.3	+0.4	-5.0	+2.3	+1.1
8......	-0.3	-1.0	+0.7	0.0	-0.6	-2.1	+1.5	0.0	+0.3	-0.5	+0.4	+0.4	-3.6	+2.6	+0.4
9......	+0.2	-0.7	+1.0	-0.1	-0.2	-1.8	+1.6	0.0	-0.4	-1.3	+0.5	+0.4	-3.8	+3.1	+0.3
10......	+0.5	+0.1	+0.6	-0.2	-0.8	-1.2	+1.0	-0.1	-1.4	-1.9	+0.4	+0.1	-3.0	+2.0	-0.2
11......	+0.7	+1.0	0.0	-0.3	-0.5	-0.3	-0.1	-0.1	-2.5	-2.4	+0.1	-0.2	-1.7	0.0	-0.6
12......	+1.2	+2.0	-0.7	-0.1	-0.8	+0.6	-1.2	-0.2	-3.2	-2.8	-0.1	-0.3	-0.2	-2.0	-0.6
	24.7				23.4				21.3						

MARCH.

Hours.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a....	+2.3	+3.0	-0.7	0.0	+0.1	+0.9	-0.7	-0.1	-2.6	-2.8	+0.4	-0.2	+1.1	-1.0	-0.3
1......	+2.7	+3.3	-0.8	+0.2	+0.3	+1.4	-1.1	0.0	-2.6	-3.0	+0.3	+0.1	+1.7	-1.6	+0.3
2	+3.0	+4.1	-0.9	-0.2	+0.6	+1.8	-1.2	0.0	-2.7	-3.1	0.0	+0.4	+2.8	-2.1	+0.2
3......	+3.2	+4.2	-0.8	-0.2	+0.9	+2.0	-1.2	+0.1	-2.6	-2.8	-0.3	+0.5	+3.4	-2.3	+0.4
4......	+3.5	+4.4	-0.6	-0.3	+1.3	+2.4	-1.1	0.0	-2.4	-2.5	-0.3	+0.4	+4.1	-2.0	+0.1
5......	+3.5	+3.9	-0.2	-0.2	+1.8	+2.4	-0.7	+0.1	-1.9	-1.9	-0.2	+0.2	+4.4	-1.1	+0.1
6......	+3.3	+3.5	+0.2	0.0	+2.4	+2.2	+0.1	+0.1	-1.5	-1.2	-0.2	-0.1	+4.5	+0.1	0.0
7......	+3.1	+2.3	+0.7	+0.1	+2.9	+1.7	+1.0	+0.1	-0.6	-0.5	+0.2	-0.3	+3.5	+1.9	-0.1
8......	+2.3	+1.5	+0.8	0.0	+3.1	+1.6	+1.6	-0.1	+0.3	+0.5	0.0	-0.2	+3.6	+2.4	-0.3
9.....	+1.8	+0.8	+0.8	+0.2	+2.7	+0.9	+1.8	0.0	+1.5	+1.0	+0.4	+0.1	+2.7	+4.0	+0.3
10......	-0.6	-0.8	+0.4	-0.2	+1.6	+0.3	+1.3	0.0	+2.6	+1.6	+0.6	+0.4	+1.1	+2.3	+0.2
11......	-2.1	-1.8	-0.1	-0.2	+0.4	-0.3	+0.6	+0.1	+3.3	+2.3	+0.5	+0.5	+0.2	+1.0	+0.4
12 p....	-3.7	-2.7	-0.7	-0.3	-1.4	-0.7	-0.7	0.0	+3.4	+2.6	+0.4	+0.4	-0.8	-1.0	+0.1
1......	-4.3	-3.3	-0.8	-0.2	-2.4	-1.4	-1.1	+0.1	+3.2	+2.7	+0.3	+0.2	-2.0	-1.6	+0.1
2......	-4.7	-3.8	-0.9	0.0	-3.0	-1.9	-1.2	+0.1	+2.7	+2.8	0.0	-0.1	-2.9	-2.1	0.0
3......	-4.8	-4.1	-0.8	+0.1	-3.3	-2.2	-1.2	+0.1	+2.1	+2.7	-0.3	-0.3	-3.6	-2.3	-0.1
4......	-4.7	-4.1	-0.6	0.0	-3.4	-2.2	-1.1	-0.1	+1.7	+2.2	-0.3	-0.2	-4.1	-2.0	-0.3
5......	-3.9	-3.9	-0.2	+0.2	-3.1	-2.4	-0.7	0.0	+1.5	+1.6	-0.2	+0.1	-4.7	-1.1	+0.3
6......	-2.9	-2.5	+0.2	-0.2	-2.2	-2.3	+0.1	0.0	+1.2	+1.0	-0.2	+0.4	-3.8	+0.1	+0.2
7......	-1.8	-2.3	+0.7	-0.2	-1.0	-2.1	+1.0	+0.1	+0.9	+0.2	+0.2	+0.5	-4.2	+1.9	+0.4
8......	-0.7	-1.2	+0.8	-0.3	+0.1	-1.5	+1.6	0.0	+0.3	-0.1	0.0	+0.4	-2.8	+2.4	+0.1
9......	+0.3	-0.3	+0.8	-0.2	+0.8	-1.1	+1.8	+0.1	-0.7	-1.3	+0.4	+0.2	-2.7	+4.0	+0.1
10......	+1.3	+0.9	+0.4	0.0	+0.9	-0.5	+1.3	+0.1	-1.5	-2.0	+0.6	-0.1	-1.6	+2.3	0.0
11......	+1.9	+1.9	-0.1	+0.1	+0.7	0.0	+0.6	+0.1	-2.3	-2.5	+0.5	-0.3	-0.6	+1.0	-0.1
12......	+2.3	+3.0	-0.7	0.0	+0.1	+0.9	-0.7	-0.1	-2.6	-2.8	+0.4	-0.2	+1.1	-1.0	-0.3
	30.3				28.6				26.3						

important differences exist between these two sets of stations, the plateau computation is not reproduced in this paper. The separation of the wave of ΔB into components was accomplished by the precepts,

$$\text{semidiurnal wave} = \text{II} = \frac{12a+12p}{2},\ \frac{1a+1p}{2},\ \text{etc.,}$$

$$\text{tridiurnal wave} = \text{III} = \frac{12a+8a+4p}{3},\ \frac{1a+9a+5p}{3},\ \text{etc.,}$$

$$\text{diurnal} = \text{I} = \Delta B - (\text{II} + \text{III}) \text{ at each hour.}$$

The pressure ΔB, Table 1, and the temperature ΔT, Table 2, were each computed in the same way. ΔB is given in units of 0.001 inch of mercury; ΔT is in units of one degree Fahrenheit; the height is in meters, as in the Blue Hill mixed system of units. In order to make the temperature curves directly comparable with the pressure curves on the diagrams, the sign of the ΔT was reversed in the beginning, so that the entire temperature computation should have opposite signs to give the natural actual values. The mean daily value of the temperature T is given for each month under the column ΔT, so that by reversing the signs of ΔT and adding to T the actual hourly temperatures which were used may be recovered.

The component curves of ΔB, I, II, III are to be found at the top of the sections of figs. 26-37, one for each month of

TABLE 2.—*Diurnal, semidiurnal, and tridiurnal temperature waves*—Cont'd.

APRIL.

Hours.	195 meters.				400 meters.				1000 meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a	+3.1	+4.8	−1.2	−0.5	+0.6	+2.1	−0.9	−0.6	−1.9	−1.7	0.0	−0.2	+5.2	−2.1	−1.3
1	+4.1	+5.6	−1.4	−0.1	+1.2	+2.7	−1.3	−0.2	−1.5	−1.7	+0.2	0.0	+6.6	−2.5	−0.3
2	+4.8	+6.0	−1.4	+0.2	+1.7	+3.3	−1.5	−0.1	−1.3	−1.6	+0.1	+0.1	+7.7	−2.8	+0.2
3	+5.2	+6.1	−1.1	+0.2	+2.4	+2.8	−1.3	+0.9	−1.0	−1.2	−0.1	+0.3	+7.7	−2.5	+1.4
4	+5.3	+5.7	−0.6	+0.2	+2.6	+3.1	−0.9	+0.4	−0.6	−0.9	−0.1	+0.4	+7.9	−1.0	+1.0
5	−5.1	+4.9	+0.3	−0.1	+2.7	+2.7	−0.1	+0.1	−0.4	−0.5	−0.2	+0.3	+7.1	0.0	+0.3
6	+4.5	+3.9	+0.8	−0.2	+2.6	+2.6	+0.2	−0.2	−0.1	−0.2	0.0	+0.1	+6.3	+1.0	−0.3
7	+3.3	+2.5	+1.2	−0.4	+2.5	+1.9	+1.1	−0.5	+0.4	+0.3	+0.2	−0.1	+4.7	+2.5	−1.0
8	+1.8	+1.1	+1.2	−0.5	+2.0	+2.0	+0.6	−0.6	+0.9	+0.7	+0.4	−0.2	+3.8	+2.2	−1.3
9	+0.3	−0.6	+1.0	−0.1	+1.2	+1.3	+0.1	−0.2	+1.5	+0.9	+0.6	0.0	+1.6	+1.7	−0.3
10	−1.7	−2.2	+0.3	+0.2	+0.2	−0.3	+0.6	−0.1	+1.7	+1.2	+0.4	+0.1	−1.3	+1.3	+0.2
11	−3.6	−3.4	−0.4	+0.2	−0.9	−1.9	+0.1	+0.9	+1.8	+1.3	+0.2	+0.3	−4.0	−0.1	+1.4
12 p	−5.4	−4.4	−1.2	+0.2	−2.4	−1.9	−0.9	+0.4	+1.9	+1.5	0.0	+0.4	−4.8	−2.1	+1.0
1	−6.9	−5.4	−1.4	−0.1	−3.8	−2.6	−1.3	+0.1	+1.8	+1.3	+0.2	+0.3	−6.7	−2.5	+0.3
2	−7.5	−5.9	−1.4	−0.2	−4.6	−2.9	−1.5	−0.2	+1.4	+1.2	+0.1	+0.1	−7.6	−2.8	−0.3
3	−7.4	−5.9	−1.1	−0.4	−5.0	−3.2	−1.3	−0.5	+0.9	+1.1	−0.1	−0.1	−8.0	−2.5	−1.0
4	−6.5	−5.4	−0.6	−0.5	−4.4	−2.9	−0.9	−0.6	+0.4	+0.7	−0.1	−0.2	−7.6	−1.6	−1.3
5	−4.6	−4.8	+0.3	−0.1	−2.9	−2.6	−0.1	−0.2	0.0	+0.2	−0.2	0.0	−7.2	0.0	−0.3
6	−2.6	−3.6	+0.8	+0.2	−2.2	−2.3	+0.2	−0.1	−0.1	0.0	0.0	+0.1	−5.9	+1.0	+0.2
7	−0.9	−2.3	+1.2	+0.2	+0.3	−1.7	+1.1	+0.9	0.0	−0.5	+0.2	+0.3	−4.5	+2.5	+1.4
8	+0.6	−0.8	+1.2	+0.2	+0.9	−0.1	+0.6	+0.4	−0.1	−0.9	+0.4	+0.4	−1.8	+2.2	+1.0
9	+1.6	+0.7	+1.0	−0.1	+1.3	+1.1	+0.1	+0.1	−0.4	−1.3	+0.6	+0.3	+0.5	+1.7	+0.3
10	+2.3	+2.2	−0.3	−0.2	+1.3	+0.9	+0.6	−0.2	−1.0	−1.5	+0.4	+0.1	+1.6	+1.3	−0.3
11	+2.8	+3.6	−0.4	−0.4	+1.0	+1.4	+0.1	−0.5	−1.5	−1.6	+0.2	−0.1	+3.4	−0.1	−1.0
12	+3.1	+4.8	−1.2	−0.5	+0.6	+2.1	−0.9	−0.6	−1.9	−1.7	0.0	−0.2	+5.2	−2.1	−1.3
	42.6				40.6				36.9						

MAY.

Hours.	195 meters.				400 meters.				1000 meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a	+4.5	+5.3	−0.6	−0.2	−0.5	−0.2	−0.5	+0.2	−0.8	−0.7	−0.2	+0.1	+4.4	−1.3	+0.1
1	+4.6	+6.1	−1.0	−0.5	−0.7	+0.3	−1.3	+0.3	−0.8	−0.4	−0.5	+0.1	+6.0	−2.8	−0.1
2	+4.7	+6.4	−1.3	−0.4	−0.9	+0.6	−1.7	+0.2	−0.8	−0.1	−0.8	+0.1	+6.9	−3.8	−0.1
3	+4.8	+6.4	−1.3	−0.3	−0.8	+1.1	−1.8	−0.1	−0.7	+0.3	−1.0	0.0	+7.8	−4.1	−0.4
4	+4.8	+5.9	−1.0	−0.1	−0.5	+1.2	−1.5	−0.2	−0.3	+0.8	−1.0	−0.1	+7.9	−3.5	−0.4
5	+4.5	+5.0	−0.5	0.0	+0.5	+1.4	−0.7	−0.2	+0.6	+1.1	−0.5	0.0	+7.5	−1.7	−0.2
6	+3.9	+4.7	+0.2	0.0	+1.6	+1.3	+0.4	−0.1	+1.4	+1.1	+0.2	+0.1	+7.1	+0.8	0.0
7	+2.8	+2.3	+0.7	−0.2	+2.8	+1.3	+1.3	+0.2	+2.2	+1.4	+0.7	+0.1	+5.0	+2.7	+0.1
8	+1.5	+0.7	+1.0	−0.2	+3.6	+1.3	+2.1	+0.2	+2.7	+1.5	+1.1	+0.1	+3.5	+4.2	+0.1
9	−0.5	−0.9	+0.9	−0.5	+3.3	+1.0	+2.0	+0.3	+2.7	+1.4	+1.2	+0.1	+1.5	+4.1	−0.1
10	−2.5	−2.5	+0.4	−0.4	+2.4	+0.7	+1.5	+0.2	+2.1	+1.1	+0.9	+0.1	−0.7	+2.8	−0.1
11	−4.2	−3.1	−0.2	−0.3	+0.8	+0.2	+0.7	−0.1	+1.4	+1.0	+0.4	0.0	−1.9	+0.9	−0.4
12 p	−5.6	−4.9	−0.6	−0.1	−0.5	+0.2	−0.5	−0.2	+0.5	+0.8	−0.2	−0.1	−3.9	−1.3	−0.4
1	−6.6	−5.5	−1.0	0.0	−1.8	−0.3	−1.3	−0.2	−0.1	+0.4	−0.5	0.0	−5.5	−2.8	−0.2
2	−7.2	−5.9	−1.3	0.0	−2.5	−0.7	−1.7	−0.1	−0.8	−0.1	−0.8	+0.1	−6.7	−3.8	0.0
3	−7.3	−5.8	−1.3	−0.2	−2.8	−1.2	−1.8	+0.2	−1.2	−0.3	−1.0	+0.1	−7.3	−4.1	+0.1
4	−6.7	−5.5	−1.0	−0.2	−2.5	−1.2	−1.5	+0.2	−1.7	−0.8	−1.0	+0.1	−7.5	−3.5	+0.1
5	−5.5	−4.5	−0.5	−0.5	−1.8	−1.4	−0.7	+0.3	−1.6	−1.2	−0.5	+0.1	−7.1	−1.7	−0.1
6	−3.5	−3.3	+0.2	−0.4	−0.9	−1.5	+0.4	+0.2	−1.1	−1.4	+0.2	+0.1	−6.2	+0.8	−0.1
7	−1.5	−1.9	+0.7	−0.3	−0.2	−1.4	+1.3	−0.1	−0.8	−1.5	+0.7	0.0	−4.8	+2.7	−0.4
8	+0.5	−1.4	+1.0	−0.1	+0.5	−1.4	+2.1	−0.2	−0.5	−1.5	+1.1	−0.1	−4.3	+4.2	−0.4
9	+2.2	+1.3	+0.9	0.0	+0.6	−1.2	+2.0	−0.2	−0.4	−1.6	+1.2	0.0	−1.5	+4.1	−0.2
10	+3.2	+3.6	+0.4	0.0	+0.5	−0.9	+1.5	−0.1	−0.4	−1.4	+0.9	+0.1	+1.3	+2.8	0.0
11	+3.9	+4.3	−0.2	−0.2	+0.5	−0.4	+0.7	+0.2	−0.6	−1.1	+0.4	+0.1	+2.8	+0.9	+0.1
12	+4.5	+5.3	−0.6	−0.2	−0.5	−0.2	−0.5	+0.2	−0.8	−0.7	−0.2	+0.1	+4.4	−1.3	+0.1
	54.5				54.5				47.2						

JUNE.

Hours.	195 meters.				400 meters.				1000 meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a	+4.2	+5.5	−0.6	−0.7	+1.7	+2.6	−0.3	−0.6	+1.4	+1.1	+0.5	−0.2	+9.2	−0.4	−1.5
1	+4.9	+5.7	−0.5	−0.3	+1.9	+3.2	−0.8	−0.5	+1.7	+1.5	+0.2	0.0	+10.4	−1.1	−0.8
2	+5.3	+6.7	−1.3	−0.1	+2.3	+3.5	−1.1	−0.1	+2.1	+2.2	−0.2	+0.1	+12.4	−2.6	−0.1
3	+5.5	+6.8	−1.3	0.0	+2.6	+3.6	−1.3	+0.3	+2.4	+2.4	−0.4	+0.4	+12.8	−3.0	+0.7
4	+5.3	+6.4	−1.2	+0.1	+2.7	+3.6	−1.3	+0.4	+2.4	+2.4	−0.5	+0.5	+12.5	−3.0	+1.0
5	+4.9	+5.2	−0.5	+0.2	+2.8	+3.9	−1.3	+0.2	+2.4	+2.2	−0.3	+0.5	+11.3	−2.1	+0.9
6	+3.9	+5.2	+0.1	−0.4	+2.7	−2.7	+0.1	−0.1	+2.3	+2.1	0.0	+0.2	+8.0	+0.2	−0.3
7	+2.8	+2.9	+0.5	−0.6	+2.5	+1.8	+1.0	−0.3	+2.0	+1.6	+0.4	0.0	+6.3	+1.9	−0.9
8	+1.3	+1.2	+0.8	−0.7	+1.7	+1.1	+1.2	−0.6	+1.4	+1.2	+0.4	−0.2	+3.5	+2.4	−1.5
9	+0.1	−0.4	+0.8	−0.3	+0.9	+1.3	+1.1	−0.5	+1.2	+0.4	+0.8	0.0	+1.3	+2.7	−0.8
10	−1.8	−2.1	+0.4	−0.1	0.0	−0.7	+0.8	−0.1	+0.6	−0.1	+0.6	+0.1	−2.9	+1.8	−0.1
11	−3.7	−3.8	+0.1	0.0	−1.1	−1.7	+0.3	+0.3	+0.2	−0.6	+0.4	+0.4	−6.1	+0.8	+0.7
12 p	−5.3	−4.8	−0.6	+0.1	−2.3	−2.4	−0.3	+0.4	−0.4	−1.4	+0.5	−0.5	−8.6	−0.4	+1.0
1	−5.8	−5.5	−0.5	+0.2	−3.5	−2.9	−0.8	+0.2	−1.4	−2.1	+0.2	+0.5	−10.5	−1.1	+0.9
2	−7.8	−6.1	−1.3	−0.4	−4.5	−8.3	−1.1	−0.1	−2.4	−2.4	−0.2	+0.2	−11.8	−2.6	−0.3
3	−8.1	−6.2	−1.3	−0.6	−5.2	−3.6	−1.3	−0.3	−3.1	−2.7	−0.4	0.0	−12.5	−3.0	−0.9
4	−7.6	−5.7	−1.2	−0.7	−5.3	−3.4	−1.3	−0.6	−3.5	−2.8	−0.5	−0.2	−10.9	−3.0	−1.5
5	−5.8	−5.0	−0.5	−0.3	−4.3	−2.5	−1.3	−0.5	−3.0	−2.7	−0.3	0.0	−10.2	−2.1	−0.8
6	−3.8	−3.8	+0.1	−0.1	−2.5	−2.5	+0.1	−0.1	−2.3	−2.4	0.0	+0.1	−8.7	+0.2	−0.1
7	−1.8	−2.3	+0.5	0.0	−0.5	−1.8	+1.0	+0.3	−1.3	−2.1	+0.4	+0.4	−6.2	+1.9	+0.7
8	+0.2	−0.7	+0.8	+0.1	+0.7	−0.9	+1.2	+0.4	−0.6	−1.5	+0.4	+0.5	−3.1	+2.4	+1.0
9	+1.5	+0.5	+0.8	+0.2	+1.3	0.0	+1.1	+0.2	+0.4	−0.9	+0.8	+0.5	−0.4	+2.7	+0.9
10	+2.6	+2.6	+0.4	−0.4	+1.5	+0.8	+0.8	−0.1	+0.7	−0.1	+0.6	+0.2	+3.3	+1.8	−0.3
11	+3.5	+3.0	+0.1	−0.6	+1.7	+1.7	+0.3	−0.3	+1.2	+0.8	+0.4	0.0	+5.5	+0.8	−0.9
12	+4.2	+5.5	−0.6	−0.7	+1.7	+2.6	−0.3	−9.6	+1.4	+1.1	+0.5	−0.2	+9.2	−0.4	−1.5
	62.2				60.7				54.4						

TABLE 2.—*Diurnal, semidiurnal, and tridiurnal temperature waves*—Cont'd.

JULY.

Hours.	195 Meters.				400 Meters.				1000 Meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a	+3.8	+5.2	−1.2	−0.2	+0.2	+0.8	−0.4	−0.2	0.0	+0.3	−0.1	−0.2	+6.3	−1.7	−0.6
1	+4.5	+5.9	−1.4	0.0	+1.2	+1.5	−0.2	−0.1	+0.8	+0.8	+0.1	−0.1	+8.2	−1.5	−0.2
2	+5.0	+6.3	−1.3	0.0	+2.1	+2.1	0.0	0.0	+1.6	+1.5	+0.2	−0.[illegible]	+9.9	−1.1	−0.1
3	+5.2	+6.5	−1.2	0.0	+2.9	+2.6	+0.2	+0.1	+2.3	+2.3	+0.1	−0.1	+11.4	−0.9	0.0
4	+5.3	+6.2	−0.7	−0.2	+3.3	+3.1	+0.2	0.0	+2.8	+2.5	+0.2	+0.1	+11.8	−0.3	−0.1
5	+5.0	+5.3	−0.1	−0.2	+3.3	+3.0	+0.2	+0.1	+2.8	+2.7	−0.1	+2.0	+11.0	0.0	+0.1
6	+4.4	+4.4	+0.6	−0.6	+3.1	+2.9	+0.1	+0.1	+2.6	+2.7	−0.2	+0.1	+10.0	+0.5	−0.4
7	+3.5	+2.5	+1.3	−0.3	+2.8	+2.6	+0.1	+0.1	+2.4	+2.6	−0.2	0.0	+7.7	+1.2	−0.2
8	+2.4	+1.2	+1.4	−0.2	+2.1	+2.4	−0.1	−0.2	+1.8	+2.2	−0.2	−0.[illegible]	+5.8	+1.1	−0.6
9	+0.7	−0.5	+1.2	0.0	+1.5	+1.5	+0.1	−0.1	+1.6	+1.5	+0.1	−0.1	+2.5	+1.4	−0.2
10	−1.8	−1.6	−0.2	0.0	+0.7	+0.6	+0.1	0.0	+0.8	+1.0	−0.1	−0.[illegible]	0.0	−0.2	−0.1
11	−4.1	−3.6	−0.5	0.0	0.0	−0.1	0.0	+0.1	+0.2	+0.4	−0.1	−0.1	−3.3	−0.6	0.0
12 p	−6.2	−4.8	−1.2	−0.2	−1.0	−0.6	−0.4	0.0	−0.2	−0.2	−0.1	+0.[illegible]	−5.6	−1.7	−0.1
1	−7.2	−5.6	−1.4	−0.2	−1.5	−1.4	−0.2	+0.1	−0.7	−1.0	+0.1	+0.2	−8.0	−1.5	+0.1
2	−7.6	−5.7	−1.3	−0.6	−2.1	−2.2	0.0	+0.1	−1.4	−1.7	+0.2	+0.[illegible]	−9.6	−1.1	−0.4
3	−7.5	−6.0	−1.2	−0.3	−2.6	−2.9	+0.2	+0.1	−2.1	−2.2	+0.1	0.0	−11.1	−0.9	−0.2
4	−6.7	−5.8	−0.7	−0.2	−2.9	−2.9	+0.2	−0.2	−2.4	−2.4	+0.2	−0.[illegible]	−11.1	−0.3	−0.6
5	−5.2	−5.1	−0.1	0.0	−3.0	−3.1	+0.2	−0.1	−2.9	−2.7	−0.1	−0.1	−10.9	0.0	−0.2
6	−3.2	−3.8	+0.6	0.0	−2.9	−3.0	+0.1	0.0	−2.9	−2.6	−0.2	−0.1	−9.4	+0.5	−0.1
7	−1.0	−2.3	+1.3	0.0	−2.7	−2.9	+0.1	+0.1	−2.8	−2.5	−0.2	−0.[illegible]	−7.7	+1.2	0.0
8	+0.4	−0.8	+1.4	−0.2	−2.2	−2.1	−0.1	0.0	−2.2	−2.1	−0.2	+0.1	−5.0	+1.1	−0.1
9	+1.7	+0.7	+1.2	−0.2	−1.4	−1.6	+0.1	+0.1	−1.5	−1.8	+0.1	+0.[illegible]	−2.7	+1.4	+0.1
10	+1.5	+2.3	−0.2	−0.6	−0.6	−0.8	+0.1	+0.1	−0.9	−0.9	−0.1	+0.1	+0.6	−0.2	−0.4
11	+3.1	+3.9	−0.5	−0.3	0.0	−0.1	0.0	+0.1	−0.3	−0.4	−0.1	0.0	+3.4	−0.6	−0.2
12	+3.8	+5.2	−1.2	−0.2	+0.2	+0.8	−0.4	−0.2	0.0	+0.3	−0.1	−0.[illegible]	+6.3	−1.7	−0.6
	66.8				66.0				59.8						

AUGUST.

Hours.	195 Meters.				400 Meters.				1000 Meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a	+3.2	+5.0	−1.3	−0.5	+0.5	+1.5	−0.5	−0.5	−0.6	+0.4	−0.7	−0.3	+6.5	−2.5	−1.3
1	+4.4	+5.5	−1.0	−0.1	+0.9	+2.4	−1.1	−0.3	+0.2	+1.0	−0.7	−0.1	+8.9	−2.8	−0.5
2	+4.9	+5.7	−0.8	0.0	+1.5	+2.6	−1.2	+0.1	+1.1	+1.6	−0.6	+0.1	+9.9	−2.6	+0.2
3	+5.1	+5.7	−0.7	+0.1	+2.2	+2.3	−0.5	+0.4	+1.9	+2.0	−0.3	+0.2	+10.0	−1.5	+0.7
4	+5.2	+5.5	−0.4	+0.1	+2.5	+2.5	−0.5	+0.5	+2.2	+2.2	−0.2	+0.2	+10.2	−1.1	+0.8
5	+4.6	+4.3	+0.3	0.0	+2.7	+2.4	+0.1	+0.2	+2.4	+2.1	+0.2	+0.1	+8.8	+0.6	+0.3
6	+3.8	+3.1	+0.8	−0.1	+2.5	+2.0	+0.6	−0.1	+2.4	+2.2	+0.3	−0.1	+7.3	+1.7	−0.3
7	+2.4	+1.8	+0.9	−0.3	+2.2	+1.3	+1.0	−0.1	+2.3	+1.9	+0.6	−0.2	+5.0	+2.5	−0.6
8	+1.2	+0.7	+1.0	−0.5	+1.5	+1.0	+1.0	−0.5	+2.2	+1.8	+0.7	−0.3	+3.5	+2.7	−1.3
9	−0.8	−1.2	+0.5	−0.1	+1.0	+0.3	+1.0	−0.3	+1.7	+2.2	+0.6	−0.1	+0.3	+2.1	−0.5
10	−2.6	−2.5	−0.1	0.0	0.0	−0.6	+0.5	+0.1	+0.9	+0.5	+0.3	+0.1	−2.6	+0.7	−0.2
11	−4.2	−3.7	−0.6	+0.1	−0.7	−1.2	+0.1	+0.4	0.0	0.0	−0.2	+0.2	−4.9	−0.7	+0.7
12 p	−5.8	−4.6	−1.3	+0.1	−1.5	−2.5	−0.5	+0.5	−0.8	−0.3	−0.7	+0.2	−7.4	−2.5	+0.8
1	−6.3	−5.3	−1.0	0.0	−3.0	−2.1	−1.1	+0.2	−1.6	−1.0	−0.7	+0.1	−8.4	−2.8	+0.3
2	−6.5	−5.6	−0.8	−0.1	−3.8	−2.5	−1.2	−0.1	−2.2	−1.5	−0.6	−0.[illegible]	−9.6	−2.6	−0.3
3	−6.4	−5.4	−0.7	−0.3	−3.2	−2.6	−0.5	−0.1	−2.5	−2.0	−0.3	−0.2	−10.0	−1.5	−0.6
4	−5.8	−4.9	−0.4	−0.5	−3.5	−2.5	−0.5	−0.5	−2.6	−2.1	−0.2	−0.3	−9.5	−1.1	−1.3
5	−4.0	−4.2	+0.3	−0.1	−2.5	−2.3	+0.1	−0.3	−2.1	−2.2	+0.2	−0.1	−8.7	+0.6	−0.5
6	−2.2	−3.0	+0.8	−0.0	−1.3	−2.0	+0.6	+0.1	−1.8	−2.3	+0.3	+0.1	−7.3	+1.7	+0.2
7	−0.6	−1.6	+0.9	+0.1	−0.2	−1.6	+1.0	+0.4	−1.2	−2.0	+0.6	+0.2	−5.2	+2.5	+0.7
8	+0.8	−0.3	+1.0	+0.1	+0.5	−1.0	+1.0	+0.5	−0.8	−1.7	+0.7	+0.2	−3.0	+2.7	+0.8
9	+1.8	+1.3	+0.5	0.0	+0.9	−0.3	+1.0	+0.2	−0.5	−1.2	+0.6	+0.1	−0.2	+2.1	+0.3
10	+2.4	+2.6	−0.1	−0.1	+0.9	+0.5	+0.5	−0.1	−0.4	−0.6	+0.3	−0.1	+2.5	+0.7	−0.3
11	+3.0	+3.9	−0.6	−0.3	+0.8	+0.8	+0.1	−0.1	−0.3	+0.1	−0.2	−0.2	+4.8	−0.7	−0.6
12	+3.2	+5.0	−1.3	−0.5	+0.5	+1.5	−0.5	−0.5	−0.6	+0.4	−0.7	−0.3	+6.9	−2.5	−1.3
	65.2				64.5				57.2						

SEPTEMBER.

Hours.	195 Meters.				400 Meters.				1000 Meters.				Sums.		
	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	ΔT.	I.	II.	III.	I.	II.	III.
12 a	+2.5	+3.7	−1.2	0.0	−0.6	+0.5	−1.0	−0.1	−0.7	+0.3	−0.7	−0.3	+4.5	−2.9	−0.4
1	+3.0	+4.5	−1.3	−0.2	−1.0	+0.3	−1.3	0.0	−0.7	+0.3	−0.9	−0.1	+5.1	−3.5	−0.3
2	+3.4	+4.7	−1.1	−0.3	−1.1	+0.5	−1.5	−0.1	−0.6	+0.6	−1.2	0.0	+5.8	−3.8	−0.4
3	+3.7	+4.8	−0.9	−0.2	−0.9	+0.3	−1.3	+0.1	−0.4	+0.7	−1.1	0.0	+5.8	−3.3	−0.1
4	+3.8	+4.3	−0.4	−0.1	−0.4	+0.6	−0.9	−0.1	+0.3	+0.8	−0.7	+0.2	+5.7	−2.0	0.0
5	+4.0	+3.7	+0.3	0.0	+0.2	+0.3	−0.2	+0.1	+1.0	+0.8	0.0	+0.2	+4.8	+0.1	+0.3
6	+3.7	+2.8	+0.8	+0.1	+0.8	+0.1	+0.6	+0.1	+1.3	+0.8	+0.5	0.0	+3.7	+1.6	+0.2
7	+3.0	+1.8	+1.2	0.0	+1.4	0.0	+1.3	+0.1	+1.5	+1.0	+0.6	−0.1	+2.8	+3.1	0.0
8	+2.1	+0.7	+1.4	0.0	+1.6	+0.1	+1.6	−0.1	+1.5	+0.6	+1.2	−0.3	+1.4	+4.2	−0.4
9	0.0	−0.6	+0.8	−0.2	+1.6	0.0	+1.6	0.0	+1.3	+0.4	+1.0	−0.1	−0.2	+3.5	−0.3
10	−2.2	−1.9	0.0	−0.3	+0.9	−0.2	+1.2	−0.1	+0.8	+0.2	+0.6	0.0	−1.9	+1.8	−0.4
11	−3.7	−2.9	−0.6	−0.2	+0.1	−0.2	+0.4	+0.1	+0.2	+0.1	+0.1	0.0	−3.0	−0.5	−0.1
12 p	−4.9	−3.6	−1.2	0.0	−1.4	−0.3	−1.0	−0.1	−0.6	−0.1	−0.7	+0.2	−4.0	−2.9	0.0
1	−5.5	−4.2	−1.3	0.0	−1.6	−0.4	−1.3	+0.1	−1.1	−0.4	−0.9	+0.2	−5.0	−3.5	+0.3
2	−5.5	−4.5	−1.1	+0.1	−1.8	−0.4	−1.5	+0.1	−1.7	−0.5	−1.2	0.0	−5.4	−3.8	+0.2
3	−5.4	−4.5	−0.9	0.0	−1.7	−0.5	−1.3	+0.1	−1.8	−0.6	−1.1	−0.1	−5.6	−3.3	0.0
4	−4.6	−4.2	−0.4	0.0	−1.4	−0.4	−0.9	−0.1	−1.7	−0.7	−0.7	−0.3	−5.3	−2.0	−0.4
5	−3.5	−3.6	+0.3	−0.2	−0.6	−0.4	−0.2	0.0	−1.0	−0.9	0.0	−0.1	−4.9	+0.1	−0.3
6	−2.1	−2.7	+0.8	−0.3	+0.4	−0.1	+0.6	−0.1	−0.3	−0.8	+0.5	0.0	−3.6	+1.6	−0.4
7	−0.7	−1.7	+1.2	−0.2	+1.2	−0.2	+1.3	+0.1	+0.3	−0.3	+0.6	0.0	−2.2	+3.1	−0.1
8	+0.7	−0.6	+1.4	−0.1	+1.6	+0.1	+1.6	−0.1	+0.8	−0.6	+1.2	+0.2	−1.1	+4.2	0.0
9	+1.5	+0.7	+0.8	0.0	+1.6	−0.1	+1.6	+0.1	+0.7	−0.5	+1.0	+0.2	+0.1	+3.4	+0.3
10	+2.2	+2.1	0.0	+0.1	+1.4	+0.1	+1.2	+0.1	+0.3	−0.3	+0.6	0.0	+1.9	+1.8	+0.2
11	+2.4	+3.0	−0.6	0.0	+0.6	+0.1	+0.4	+0.1	−0.1	−0.3	+0.1	−0.1	+2.8	−0.5	0.0
12	+2.5	+3.7	−1.2	0.0	−0.6	+0.5	−1.0	−0.1	−0.7	+0.3	−0.7	−0.3	+4.5	−2.9	−0.4
	58.5				57.6				51.3						

the year. The following characteristics of these waves may be noted.

Diurnal wave.—In January the amplitude, a_1, is about 0.011 inch, and this increases to 0.018 in August, which seems to be the maximum. The phase of the maximum in January is at 6–7 a. m., and that of the minimum is at 6–7 in the evening. The morning maximum phase is, apparently, about one hour later, 7–8 a. m. in the summer, and the evening minimum phase is, also, one hour later, 7–8 p. m. Thus, there is a slight advance of one hour in the times of maximum and minimum in passing from the cold season, with the sun in the Southern Hemisphere, to the warm season, with the sun in the Northern Hemisphere.

TABLE 2.—*Diurnal, semidiurnal, and tridiurnal temperature waves*—Cont'd.

OCTOBER.

Hour.	195 meters. ΔT.	I.	II.	III.	400 meters. ΔT.	I.	II.	III.	1000 meters. ΔT.	I.	II.	III.	Sums. I.	II.	III.
12 a.	+1.6	+3.0	−1.2	−0.2	−1.3	−0.5	−0.8	0.0	−2.1	−1.5	−0.8	+0.2	+1.0	−2.8	0.0
1	+2.3	+3.7	−1.2	−0.2	−1.6	−0.6	−1.2	+0.2	−2.1	−1.5	−0.9	+0.3	+1.6	−3.3	+0.3
2	+2.9	+3.8	−0.9	−0.0	−1.9	−0.7	−4.4	+0.2	−2.0	−1.4	−0.8	+0.2	+1.7	−3.1	+0.4
3	+3.4	+4.0	+0.6	0.0	−1.8	−0.7	−1.2	+0.1	−1.7	−1.2	−0.6	+0.1	+2.1	−2.4	+0.2
4	+3.6	+3.4	+0.1	+0.1	−2.1	−0.7	−1.2	−0.2	−0.9	−1.0	0.0	+0.1	+1.7	−1.1	0.0
5	+3.5	+2.9	+0.6	0.0	−0.6	−0.6	−0.1	+0.1	0.0	−0.8	+0.6	+0.2	+1.5	+1.2	+0.1
6	+2.9	+2.1	+0.9	−0.1	+0.3	−0.4	+0.7	0.0	+0.6	−0.3	+0.9	0.0	+1.4	+2.5	−0.1
7	+2.2	+1.6	+1.0	−0.3	+1.0	−0.3	+1.4	−0.1	+1.2	+0.1	+1.1	0.0	+1.3	+3.5	−0.4
8	+1.1	+0.4	+0.9	−0.2	+1.7	0.0	+1.7	0.0	+1.7	+0.3	+1.2	+0.2	+0.7	+3.8	0.0
9	−0.4	−0.6	+0.4	−0.2	+1.7	−0.1	+1.6	+0.2	+1.8	+0.5	+1.0	+0.3	−0.2	+3.0	+0.3
10	−1.6	−1.6	−0.1	0.0	+1.3	+0.2	+0.9	+0.2	+1.5	+1.0	+0.3	+0.2	−0.3	+1.1	+0.4
11	−3.2	−2.4	−0.8	0.0	+0.5	+0.6	−0.2	+0.1	+1.0	+1.3	−0.4	+0.1	−0.5	−1.4	+0.2
12 p.	−4.0	−2.9	−1.2	+0.1	−0.3	+0.7	−0.8	−0.2	+0.5	+1.2	−0.8	+0.1	−1.0	−2.8	0.0
1	−4.6	−3.3	−1.3	0.0	−0.7	+0.4	−1.2	+0.1	+0.4	+1.1	−0.9	+0.2	−1.8	−3.3	+0.1
2	−4.6	−3.6	−0.9	−0.1	−0.8	+0.6	−1.4	0.0	+0.4	+1.2	−0.8	0.0	−1.8	−3.1	−0.1
3	−4.4	−3.6	−0.6	−0.2	−0.6	+0.7	−1.2	−0.1	+0.5	+1.1	−0.6	0.0	−1.8	−2.4	−0.4
4	−3.4	−3.3	+0.1	−0.2	−0.3	+0.9	−1.2	0.0	+0.9	+0.7	0.0	+0.2	−1.7	−1.1	0.0
5	−2.4	−2.8	+0.6	−0.2	+0.5	+0.4	−0.1	+0.2	+1.1	+0.2	+0.6	+0.3	−2.2	+1.2	+0.3
6	−1.2	−2.2	+0.9	+0.1	+1.1	+0.2	+0.7	+0.2	+1.1	0.0	+0.9	+0.2	−2.0	+2.5	+0.4
7	−0.2	−1.2	+1.0	0.0	+1.7	+0.2	+1.4	+0.1	+0.9	−0.3	+1.1	+0.1	−1.3	+3.6	+0.2
8	+0.6	−0.4	+0.9	+0.1	+1.7	+0.2	+1.7	−0.2	+0.7	−0.6	+1.2	+0.1	−0.8	+3.8	0.0
9	+1.1	+0.7	+0.4	0.0	+1.5	−0.2	+1.6	+0.1	+0.1	−1.1	+1.0	+0.2	−0.6	+3.0	+0.1
10	+1.4	+1.6	−0.1	−0.1	+0.5	−0.4	+0.9	0.0	−0.9	−1.2	+0.3	0.0	0.0	+1.1	−0.1
11	+1.6	+2.7	−0.8	−0.3	−0.8	−0.6	−0.2	−0.1	−1.8	−1.4	−0.4	0.0	+0.8	−1.4	−0.4
12	+1.6	+3.0	−1.2	−0.2	−1.3	−0.5	−0.8	0.0	−2.1	−1.6	−0.8	+0.2	+1.0	−2.8	0.0
	46.6				46.7				40.1						

NOVEMBER.

Hour.	195 meters. ΔT.	I.	II.	III.	400 meters. ΔT.	I.	II.	III.	1000 meters. ΔT.	I.	II.	III.	Sums. I.	II.	III.
12 a	+2.0	+2.8	−1.1	+0.3	−1.0	−1.1	−0.5	+0.6	−0.1	−0.1	−0.4	+0.4	+1.6	−2.0	+1.3
1	+2.1	+3.4	−1.5	+0.2	−1.6	−1.2	−0.8	+0.4	−0.2	−0.1	−0.5	+0.4	+2.1	−2.8	+1.0
2	+2.2	+3.6	−1.4	0.0	−1.9	−1.1	−0.8	0.0	−0.4	0.0	−0.5	+0.1	+2.5	−2.7	+0.1
3	+2.4	+3.9	−1.2	−0.3	−2.0	−1.0	−0.7	−0.3	−0.6	−0.1	−0.4	−0.1	+2.8	−2.3	−0.7
4	+2.8	+3.3	−0.4	−0.1	−2.0	−0.8	−0.5	−0.7	−0.7	0.0	−0.3	−0.4	+2.5	−1.2	−1.2
5	+3.0	+3.6	−0.1	−0.5	−0.9	−0.6	+0.1	−0.4	−1.2	−0.1	−0.5	−0.6	+2.9	−0.6	−1.5
6	+3.2	+2.9	+0.5	−0.2	+0.7	−0.2	+0.8	+0.1	+0.3	0.0	+0.3	0.0	+2.7	+1.6	−0.1
7	+3.5	+2.2	+1.2	+0.1	+1.5	0.0	+1.1	+0.4	+0.8	0.0	+0.6	+0.2	+2.2	+2.9	+0.7
8	+3.0	+1.2	+1.6	+0.3	+1.8	+0.3	+0.9	+0.6	+1.2	0.0	+0.8	+0.4	+1.5	+3.2	+1.3
9	+1.8	+0.4	+1.2	+0.2	+1.7	+0.6	+0.7	+0.4	+1.0	0.0	+0.6	+0.4	+1.0	+2.5	+1.0
10	−0.1	−0.7	+0.6	0.0	+1.0	+0.9	+0.1	0.0	+0.5	+0.2	+0.2	+0.1	+0.4	+0.9	+0.1
11	−2.3	−1.6	−0.4	−0.3	+0.5	+1.1	−0.3	−0.3	0.0	+0.1	0.0	−0.1	−0.4	−0.7	−0.7
12 p	−4.2	−3.0	−1.1	−0.1	0.0	+1.2	−0.5	−0.7	−0.7	+0.1	−0.4	−0.4	−1.7	−2.0	−1.2
1	−5.0	−3.0	−1.5	−0.5	+0.1	+1.3	−0.8	−0.4	−0.7	+0.4	−0.5	−0.6	−1.3	−2.8	−1.5
2	−5.0	−3.4	−1.4	−0.2	+0.3	+1.0	−0.8	+0.1	−0.5	0.0	−0.5	0.0	−2.4	−2.7	−0.1
3	−4.8	−3.7	−1.2	+0.1	+0.6	+0.9	−0.7	+0.4	−0.2	0.0	−0.4	+0.2	−2.8	−2.3	+0.7
4	−4.0	−3.9	−0.4	+0.3	+1.0	+0.9	−0.6	+0.6	+0.2	+0.1	−0.3	+0.4	−2.9	−1.2	+1.3
5	−3.2	−3.3	−0.1	+0.2	+1.0	+0.5	+0.1	+0.4	+0.3	+0.4	−0.5	+0.4	−2.4	−0.6	+1.0
6	−2.2	−2.7	+0.5	0.0	+0.9	+0.1	+0.8	0.0	+0.3	−0.1	+0.3	+0.1	−2.7	+1.6	+0.1
7	−1.1	−2.0	+1.2	−0.3	+0.6	−0.2	+1.1	−0.3	+0.3	−0.2	+0.6	−0.1	−2.4	+2.9	−0.7
8	0.0	−1.4	+1.5	−0.1	0.0	−0.2	+0.9	−0.7	+0.3	−0.1	+0.8	−0.4	−1.7	+3.2	−1.2
9	+0.6	−0.1	+1.2	−0.5	−0.4	−0.7	+0.7	−0.4	+0.2	+0.2	+0.6	−0.6	−0.6	+2.5	−1.5
10	+1.2	+0.8	+0.6	−0.2	−0.8	−1.0	+0.1	+0.1	+0.1	−0.1	+0.2	0.0	−0.3	+0.9	−0.1
11	+1.6	+1.9	−0.4	+0.1	−1.0	−1.1	−0.3	+0.4	0.0	−0.2	0.0	+0.2	+0.6	−0.7	+0.7
12	+2.0	+2.8	−1.1	+0.3	−1.0	−1.1	−0.5	+0.6	−0.1	−0.1	−0.4	+0.4	+1.6	−2.0	+1.3
	39.0				40.0				34.3						

DECEMBER.

Hour.	195 meters. ΔT.	I.	II.	III.	400 meters. ΔT.	I.	II.	III.	1000 meters. ΔT.	I.	II.	III.	Sums. I.	II.	III.
12 a	+1.2	+1.8	−0.8	+0.2	−1.7	−2.4	+0.2	+0.5	+2.1	+2.4	0.0	−0.3	+1.8	−0.6	+0.4
1	+1.3	+2.4	−1.3	+0.2	−2.0	−2.3	−0.1	+0.4	+2.3	+2.4	+0.2	−0.3	+2.5	−1.2	+0.3
2	+1.5	+2.6	−1.3	+0.2	−2.1	−2.0	−0.2	+0.1	+2.4	+2.2	+0.3	−0.1	+2.8	−1.2	+0.2
3	+1.9	+3.1	−1.1	−0.1	−2.1	−1.7	−0.3	−0.1	+2.2	+1.9	+0.3	0.0	+3.3	−1.1	−0.2
4	+2.3	+3.3	−0.8	−0.2	−2.0	−1.3	−0.4	−0.3	+2.0	+1.6	+0.3	+0.2	+3.5	−0.9	−0.3
5	+3.0	+3.2	0.0	−0.2	−0.9	−0.8	0.0	−0.1	+1.3	+1.1	+0.1	+0.1	+3.5	+0.1	−0.2
6	+3.2	+2.7	+0.6	−0.1	+0.2	−0.2	+0.2	+0.2	−0.1	+0.3	−0.3	−0.1	+2.8	+0.5	0.0
7	+3.2	+2.1	+1.1	0.0	+1.2	+0.5	+0.4	+0.3	−1.2	−0.2	−0.6	−0.4	+2.4	+0.9	−0.1
9	+3.1	+1.3	+1.6	+0.2	+2.0	+1.0	+0.6	+0.5	−1.7	−1.8	−0.6	−0.3	+1.6	+1.5	+0.4
9	+2.4	+0.9	+1.3	+0.2	+2.2	+1.3	+0.5	+0.4	−2.0	−1.2	−0.5	−0.3	+1.0	+1.3	+0.3
10	+1.1	0.0	+0.9	+0.2	+2.2	+1.7	+0.4	+0.1	−2.1	−1.7	−0.3	−0.1	0.0	+1.0	+0.2
11	−1.3	−1.0	−0.2	−0.1	+2.1	+2.0	+0.2	−0.1	−2.2	−2.0	−0.2	0.0	−1.0	−0.2	−0.2
12 p	−2.8	−3.4	−0.8	−0.2	+2.0	+2.1	+0.2	−0.3	−2.1	−2.3	0.0	+0.2	−3.6	−0.6	−0.3
1	−3.8	−4.9	−1.3	−0.2	+1.9	+2.1	−0.1	−0.1	−2.0	−2.3	+0.2	+0.1	−5.1	−1.2	−0.2
2	−4.1	−5.3	−1.3	−0.1	+1.8	+1.8	−0.2	+0.2	−1.9	−2.3	+0.3	−0.1	−5.8	−1.2	0.0
3	−4.1	−5.2	−1.1	0.0	+1.6	+1.6	−0.3	+0.3	−1.7	−1.6	+0.3	−0.4	−5.2	−1.1	−0.1
4	−3.8	−4.8	−0.8	+0.2	+1.3	+1.2	−0.4	+0.5	−1.4	−1.4	+0.3	−0.3	−5.0	−0.9	+0.4
5	−3.0	−3.2	0.0	+0.2	+0.9	+0.5	0.0	+0.4	−1.1	−0.9	+0.1	−0.3	−3.6	+0.1	+0.3
6	−2.0	−2.8	+0.6	+0.2	+0.1	−0.2	+0.2	+0.1	−0.5	−0.1	−0.3	−0.1	−3.1	+0.5	+0.2
7	−1.0	−1.5	+0.6	−0.1	−0.4	−0.7	+0.4	−0.1	−0.1	+0.5	−0.6	0.0	−1.7	+0.9	−0.2
8	0.0	−1.4	+1.6	−0.2	−1.0	−1.2	+0.5	−0.8	+0.6	+1.0	−0.6	+0.2	−1.6	+1.5	−0.3
9	+0.2	−0.9	+1.3	−0.2	−1.2	−1.6	+0.6	−0.1	+1.1	+1.5	−0.5	+0.1	−1.0	+1.3	−0.2
10	+0.6	−0.2	+0.9	−0.1	−1.5	−2.1	+0.4	+0.2	+1.6	+2.0	−0.3	−0.1	+0.1	+1.0	0.0
11	+0.9	+1.1	−0.2	0.0	−1.8	−2.3	+0.2	+0.3	+1.8	+2.4	−0.2	−0.4	+1.2	−0.2	−0.1
12	+1.2	+1.8	−0.8	+0.2	−1.7	−2.4	+0.2	+0.5	+2.1	+2.4	0.0	−0.3	+1.8	−0.6	+0.4
	28.2				30.0				23.4						

Semidiurnal wave.—The two maxima occur with remarkable steadiness at about 10 a. m. and 10 p. m. throughout the year, though they are a little later in the summer than in the winter. The minima occur at 3–4 a. m. and 3–4 p. m. in the winter, and about one hour later 4–5 a. m. and 4–5 p. m. in the summer. The ascending branch of the curve is, therefore, a little less inclined than the descending branch during the winter, but in summer they are quite symmetrical. The amplitude of the curve is about 0.018 in January and somewhat less in the summer, 0.014 in June, 0.015 in July.

Tridiurnal wave.—There is much more fluctuation in this minor wave than in the two others just described. In December, January, and February the amplitude is about 0.006, with maxima at 2 a. m., 10 a. m., 6 p. m., and minima at 6 a. m., 2 p. m., 10 p. m. On the other hand, in the summer the amplitude is about one-third as great, 0.002, but the *phase is reversed* so that the maxima occur at 7 a. m., 3 p. m., 11 p.m., with the minima at 3 a. m., 11 a. m., 7 p. m. The change of phase appears to take place between March–April, August–September, so that the larger amplitude is developed while the sun is in the Southern Hemisphere, and the smaller while it is in the northern, the transition taking place at the equinoxes as the sun crosses the equator. This is the third instance in which an inversion phenomena has been detected in the earth's atmosphere, due the orbital solar action: (1) The inversion of the magnetic and meteorological elements as described in my Bulletin No. 21; (2) the inversion or surging of the atmosphere as to its temperature between the Tropics and the temperate zones, and as to its pressure between the Eastern and the Western hemispheres, as shown in the MONTHLY WEATHER REVIEW, November 1903; and (3) in the tridiurnal pressure wave as exhibited in this paper. Whatever may be the causes of these phenomena of inversion it is evident that the mere interference of waves of different periods can not be the sole cause. The subject will require careful and exhaustive investigation of the numerous forces operating in the complex circulations of the solar and terrestrial atmospheres.

THE DIURNAL, SEMIDIURNAL, AND TRIDIURNAL TEMPERATURE WAVES IN THE LOWER STRATA OF THE ATMOSPHERE.

An inspection of the temperature curves given in the preceding paper, MONTHLY WEATHER REVIEW, February, 1905, makes it evident that the temperature waves in the successive strata of the lower atmosphere differ very much from the wave observed at the surface. We may suppose that the pressure waves are closely connected with the temperature variations in the lower strata, and that the changes in the density produced by the variations in temperature become converted into pressure changes in part by thermodynamic processes. The subject is, of course, complex, and its final solution will require more detailed examination than it has been possible to make at this time. I have decided to execute a rough sort of integration of the entire temperature effect, by computing the components for the curves deduced on the planes at 195, 400, and 1000 meters elevation. The agreement between this result and the actual one existing in the atmosphere from the surface to 3400 meters can be only approximate, but the outcome serves to indicate that the temperature waves in the free air are the direct cause of the pressure waves as a density rather than as a dynamic effect. The temperatures on these three planes were scaled from the diagrams, each one was separated into its I, II, III components, and then the sums for each type on these three planes were computed. The details of this work are given in Table 2, since they are of general interest, and the second section of the diagrams under each month in figs. 26–37 gives the corresponding temperature curves. I repeat the statement, that for convenient comparison of the temperature

waves with the pressure waves the numerical signs have been reversed throughout the temperature computation.

Diurnal wave.—These temperature waves have been constructed without using the surface temperatures, and this implies that the temperatures in the several strata are chiefly concerned in generating the pressure waves that are observed at the respective elevations. Of course some additional influence must be expected to work in from the adjacent strata not here reckoned in the integration, and therefore the results here discussed do not exhaust the entire scope of the available sources of inquiry. A close approximation to a parallelism between the pressure and the temperature systems is certainly indicated. In January, February, and March the diurnal curves of temperature and pressure are in close agreement as to amplitude and phase, and reversing the sign of ΔT, we obtain the relation,

$$-4^\circ \Delta T \propto +0.010 \Delta B, \text{ or } -1^\circ F + \propto 0.0025 \text{ inch.}$$

With the approach to summer the curve of temperature increases in amplitude more rapidly than the pressure curve, and the phase of maximum and of minimum in July and August is about three or four hours earlier, 4 a. m. for temperature and 7 a. m. for pressure, or 3:30 p. m. for temperature and 7:30 p. m. for pressure. The semidiurnal temperature waves are, however, smaller than would be expected and possibly I have not obtained exactly the correct temperature curves to resolve into components in these two months. We have an approximate relation,

$$-12^\circ \Delta T \propto +0.017 \Delta B, \text{ or } -1^\circ F \propto +0.0014 \text{ inch.}$$

It follows that in summer the influence of one degree of temperature to change the pressure is about one-half as much as it is in the winter. This implies a series of complex functions which it is not possible to discuss in this place.

Semidiurnal wave.—The most important fact brought out by this computation is that a true semidiurnal wave of temperature is developed in the lower strata whose phase for the maximum ordinate persists steadily throughout the year at 8 a. m. and 8 p. m., with the minimum at 2 a. m. and 2 p. m., except that in summer the minimum occurs about one hour earlier. Generally the temperature maxima precede the pressure maxima by about two hours, implying that the semidiurnal pressure wave follows the temperature wave at an interval of two hours throughout the year. In winter the amplitudes have nearly the following relation,

$$-3^\circ \Delta T \propto +0.018 \Delta B, \text{ or } -1^\circ F \propto +0.0030 \text{ inch,}$$

while in summer the relation is follows,

$$-2^\circ \Delta T \propto +0.015 \Delta B, \text{ or } -1^\circ F \propto +0.0075 \text{ inch.}$$

Hence, the temperature wave in summer is two and one-half times as effective in producing the pressure wave as it is in the winter. In considering the dynamic relations of these waves, it is necessary to bear in mind that the entire system is moving from east to west in the atmosphere, or from right to left in the diagram, and the relative position in the semidiurnal, as in the diurnal waves, is that the temperature waves precede the pressure waves. If a physical process is concerned, as the vertical movement of convectional currents with expanding heads, or the downward flow of cool air along the sides of the warm diurnal cone, then this time-lag of two hours represents the interval connecting the temperature cause with the pressure effect. It is, however, quite clear that the diurnal pressure waves have their origin in a temperature wave, rather than in a forced dynamic wave as suggested by Lord Kelvin.

Tridiurnal wave.—We shall divide the year into two portions for discussing the tridiurnal wave: first, October to March, and, second, April to September. In the winter period it is seen that a fair agreement exists in the phases of the maxima of the temperature and the pressure waves, and that, with the system of coordinates here employed, they are in approximately direct synchronism. In the summer months, on the other hand, although the correspondence between the two sets of curves is much less satisfactory, there is suggested a synchronism of the inverse type, such that the phases of the temperature and pressure are opposite to one another. It will hardly be safe to lay down more definite conclusions regarding these tridiurnal curves, because we should not only require to have for discussion very perfect original curves in the atmosphere, but also it would be necessary to integrate throughout the entire range in altitude—that is, through the strata of the atmosphere affected by the diurnal disturbance—instead of limiting our summation to three selected curves.

A further discussion of these curves in connection with the vapor tension, the electric potential gradient, the coefficient of dissipation, and the phenomena of atmospheric electricity generally will be found in the next paper of this series, while their relations to the diurnal variation of the earth's magnetic field will be taken up in a still later paper.

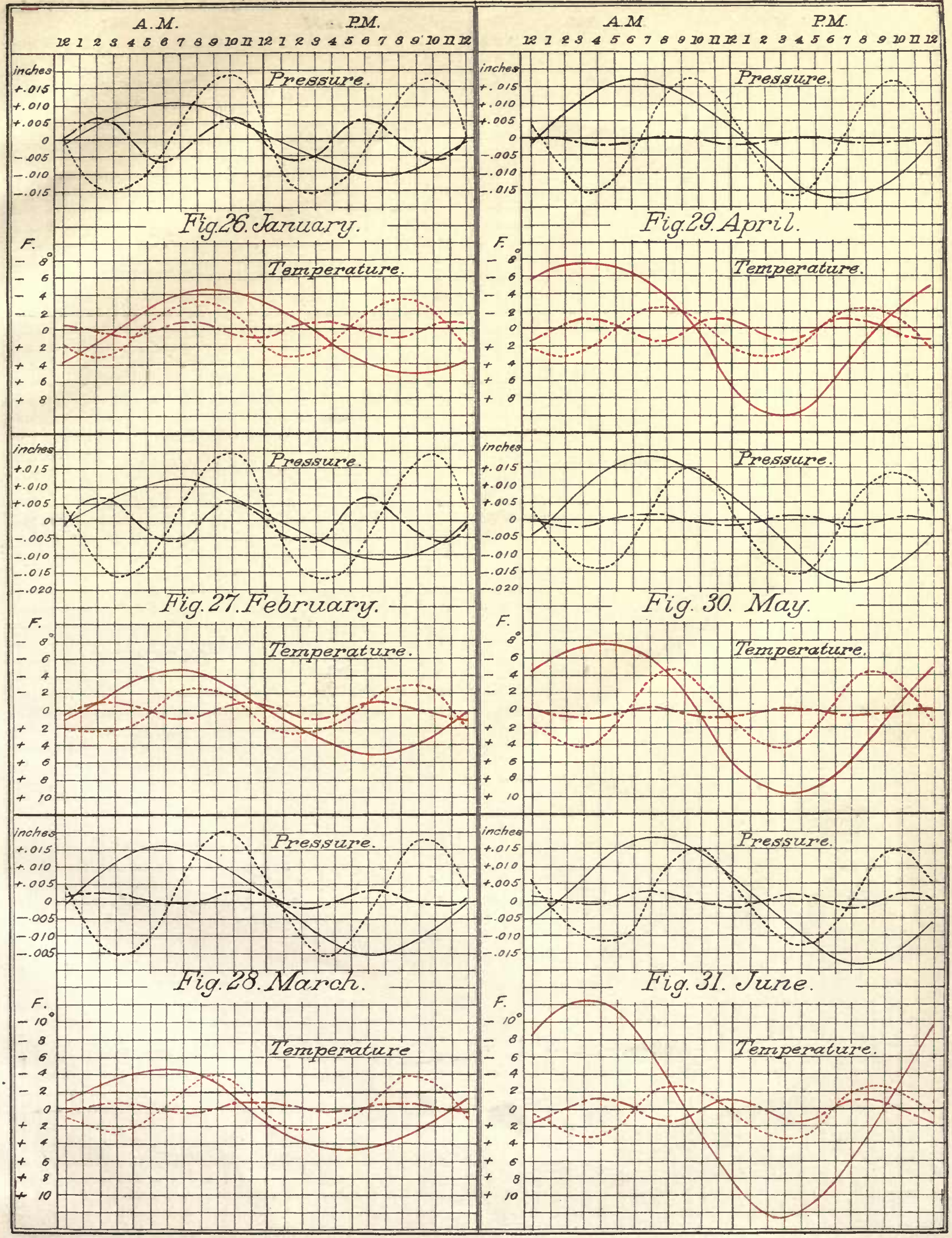


Fig. 26. January.

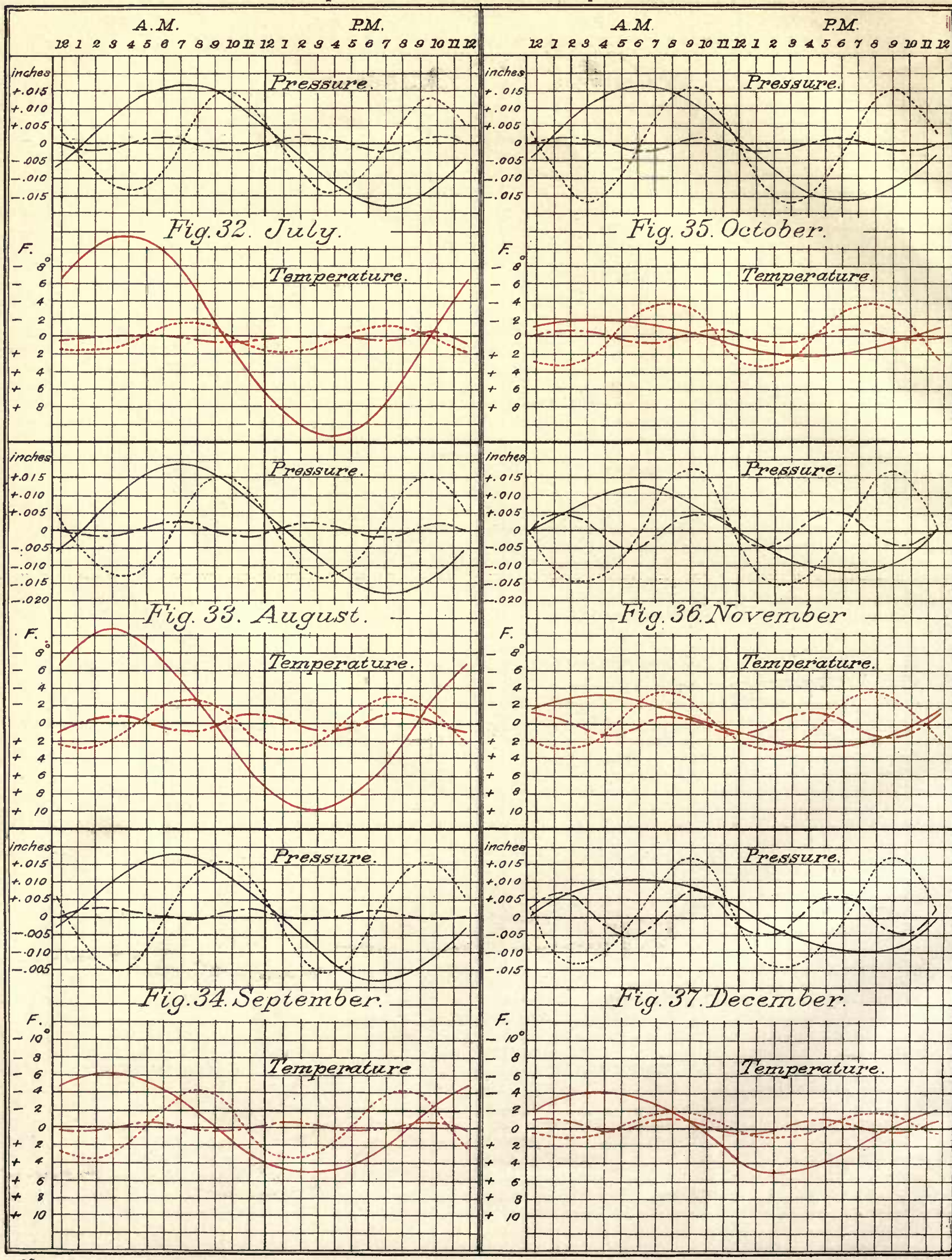
Fig. 27. February.

Fig. 28. March.

Fig. 29. April.

Fig. 30. May.

Fig. 31. June.


A.M.
P.M.
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
inches
Pressure.
Fig. 32. July.
F.
Temperature.
Fig. 35. October.
Fig. 33. August.
Fig. 36. November
Fig. 34. September.
Fig. 37. December.

III.—THE DIURNAL PERIODS OF THE VAPOR TENSION, THE ELECTRIC POTENTIAL, AND COEFFICIENT OF DISSIPATION.

THE DIURNAL VARIATION OF THE VAPOR TENSION.

In the Monthly Weather Review for December, 1902, I made some remarks upon the phenomena involved in the changes of the semidiurnal periods of the barometric pressure, the atmospheric electric potential-fall, and the vapor tension, as they occur at the surface of the earth, into the simple diurnal periods which are observed in the strata above the ground. The present series of papers properly supplements that paper, but in this connection attention is fixed upon the annual variations in these two related periodicities for the purpose of determining the exact physical processes operating to produce the transformations recorded in those periods. Especially it is proposed to lead up to an explanation of the diurnal periods in the earth's magnetic field, which seem to be simply a meteorological effect of the radiation of the sun in the lower strata of the atmosphere, through the intermediate development of currents of electric ions in connection with the prevailing distribution of the temperature.

The hourly values of the vapor tension at the surface were not available at the Blue Hill Valley Station, and I decided not to take Boston, preferring a more inland station which should be freer from seacoast influences. In consequence of the convenience of the published record at Parc St. Maur, Paris, the mean diurnal variations of vapor tension at that place for the five years, 1897–1901, were computed, the results being given in Table 3. These variations at each hour relative to the daily mean are transferred to the curves of figs. 38–49, being the lower curve of each month. In order to obtain the hourly values of the vapor tension in the free air for the levels 195, 450, and 1000 meters at Blue Hill, I proceeded as follows: The temperatures computed at these elevations in Fahrenheit degrees were read from figs. 14–25, and they may be recovered from Table 2, by reversing the sign of ΔT as there recorded. These temperatures were converted into degrees centigrade. With this as an argument the vapor tension E was taken from Table 43 in the Smithsonian Meteorological Tables, edition of 1896, for saturation. Then, with the observed relative humidity at these levels for each hour, the corresponding vapor tension, $e = E \times R.\ H.$, was computed, and the results are given in Tables 4, 5, and 6. These variations of the vapor tension above the surface are also transferred to figs. 38–49, the mean monthly values appearing on the zero line, and the ordinate divisions being 0.40 mm. The values of the relative humidity in the free air at Blue Hill were extracted from the same report, and for each month, at the levels 195, 400, 1000 meters, all the available data were collected. Certain interpolations were made from observations at other heights, when practicable, in order to obtain more material for this discussion. The means were taken at each hour, and plotted on diagrams, and average lines were drawn through the points, from which approximate values were found. Then these values of the relative humidity for the hours 12 a. m., 4 a. m., 8 a. m., 12 p. m., 4 p. m., 8 p. m., were placed on a second system of sheets with the months as one argument, and mean lines were drawn. From these curves, which smoothed out minor irregularities, the second approximate hourly values at six points were found, and transferred to the first system of curves, which were reconstructed by the aid of them. This method of double cross-plotting involving two approximations, as before stated, is capable of dealing successfully with very rough data. An examination of the set of curves in the figs. 38–49 "Diurnal variation of the vapor tension, Δe, in the four levels 50 meters, Parc St. Maur, Paris, 195 meters, Blue Hill summit, 400 and 1000 meters in the free air over Blue Hill," leads to the following remarks on the behaviour of this element in the lower atmosphere.

(1) The mean vapor tension for the day decreases from a maximum at all levels in July and August to a minimum in the same levels in February, and from a maximum at the surface in each month to a series of lower values with the increase in elevation. This course is parallel with the seasonal change in the temperature, as may be seen by comparing the series of curves in figs. 14–25. The vapor content of the atmosphere is strictly a function of the temperature and the sources of evaporation of aqueous vapor, but for any given locality it is a function of the temperature alone when general averages are considered.

(2) For the diurnal period at the surface the year divides into two portions: first, November to February, when the diurnal variation has a single maximum, about 3 p. m., and a single minimum, about 6 a. m.; second, March to October, when the semidiurnal period is developed with maxima about 8 a. m., 8 p. m., and minima at 4 a. m. and 3 p. m., approximately. In March the maxima are located more closely together, also in October, than in the other months, showing that there is in this connection a transition between the single diurnal and the semidiurnal periodic systems. By comparing these curves with the series of figs. 2–13, "Temperature-falls in the lower strata," it is seen that the fully developed maxima of the vapor tension occur exactly in the midst of the hours of the most rapid temperature changes, 8 a. m., 8 p. m. When the lower atmosphere is heating most rapidly from the surface upward, convection currents form, which rise in the forenoon, carrying the products of fresh evaporation with them as an increase in the vapor tension. The surfaces covered

with dew and moisture deposited during the night are in a favorable condition for rapid evaporation. The first heat of radiation on the ground acts primarily on the vegetation and fills the air with vapor as fast as the process of evaporation can proceed. The midday minimum occurs at the time of greatest effective temperature, but it is a minimum for the vapor tension because the supply of moisture for evaporation is not sufficient to keep the same degree of relative humidity at the higher temperature then prevailing. The vapor contents that rise in the first wave are carried aloft to about 2000 meters, or the height of the diurnal temperature effect, and there is not sufficient aqueous vapor at the surface to fill the air undergoing this rapid temperature change up to an equal relative humidity. The second maximum at the surface is due to a reverse process of cooling, which begins at the ground and occurs most rapidly at 8 p. m., as is seen from figs. 2–13. The convection currents at that hour are directed earthward and bring the aqueous vapor back to strata which are lowering their temperature, and, therefore, develop a higher relative humidity. This cooling action extends upward slowly, with a considerable time lag, until it gradually dies out within a few hundred meters of the ground. The single maximum of the upper strata seems to be the continuance of the forenoon maximum in the lower strata, and, except for June, July, and August, the afternoon second maximum does not develop higher than 400 meters. The entire system groups itself about the curves of the temperature-fall in a very harmonious manner. The vapor rises along the ascending slope of the temperature variation and falls again on the descending slope. This is seen clearly in the summer months, where the time of the sun's radiation covers the hours from 5 a. m. to 7 p. m. In the winter these hours are much contracted, and, the temperature being relatively low, the vapor tension has much less chance to produce the double maximum, since the true vertical convection currents are comparatively feeble.

(3) In the winter there is a marked inversion of the vapor tension in the stratum 195 meters, the summit of Blue Hill, as referred to that at the ground 50 meters, or at higher elevations 400, 1000 meters, such that a minimum occurs during the middle of the day and a maximum at night. This appears in December, January, February, March, and April; in the other months, the rising forenoon maximum reverses it back again. Whether this is a characteristic of the free air at this level, or is a peculiarity of Blue Hill summit, it is not easy to determine. It may be noted that while the mean vapor tension decreases with the height, the amplitude increases at the given elevations. The lower temperature of the higher strata causes the vapor tension to be more sensitive to masses intruding from below. The same amount of aqueous vapor will cause a greater change in the tension at low temperatures than at high, and hence the vapor contents rising from the ground causes greater amplitudes in the variation of the hourly values in proportion to the height. Thus, in July a temperature of 65°, with range from 56° to 78°, is accompanied by a change in the vapor tension $\Delta e = 0.70$ mm. at the ground, while at 1000 meters the mean temperature of 60°, with range from 57° to 62°, is attended by a variation $\Delta e = 3.50$ mm. There are numerous other circumstances which can be deduced from these diagrams, such as the gradients at each hour in the day between the different levels; the function of the vapor tensions relative to the temperatures in the free air; the effect of the surface in disturbing free air conditions, which it would be beyond the purpose of these papers to discuss at this time.

THE DIURNAL VARIATION OF THE ELECTRIC POTENTIAL GRADIENTS.

The three series of observations of the hourly values of the atmospheric electric potential gradient, that is, the fall in volts per meter, $-\frac{dV}{dn}$, which have been examined in this connection are those at Perpignan[1], Paris[2], and Greenwich[3] for the five years, 1896–1900, inclusive. For Perpignan and Paris the curves given in fig. 50 were copied from the diagrams contained in the works referred to above; while for Greenwich the data for the clear and rainy days combined, as well as for the clear days by themselves, were extracted from the annual reports, Tables 7, 8; the results appear for each month in fig. 51; the clear and rainy days are printed in dotted and the clear days alone in black lines. No attention has been paid to the absolute values in volts, as it is proposed simply to discuss the causes of the maxima and the minima, rather than the amplitudes of the curves. The figs. 50, 51 show that a maximum occurs during the forenoon hours, 7 to 11 a. m., and a second maximum is found in the evening hours from 6 to 11 p. m. The Perpignan and the Paris curves suggest that the morning maximum occurs earlier by about two hours in summer than in winter, while the evening maximum is more steadily centered at 7 to 8 p. m. The Greenwich curves, on the other hand, indicate that there are really two maxima in the forenoon, and two maxima in the evening, though there is a tendency to suppress the first morning maximum at 8 a. m. in the winter, which gives this maximum the appearance of entering earlier in summer than in winter as on the French curves. The evening double maximum seems to show that the 10–11 p. m. crest is steadier than the 7–8 p. m. crest throughout the year. We have therefore to give an account of the variable 8 a. m. and 8 p. m. crests, and the comparatively steady 11 a. m. and 11 p. m. crests.

Before proceeding with this exposition, I will further introduce some curves of the daily variation of the rate of dissipation of the electric charge, $q = \frac{a-}{a+}$, as given by Zölss[4], and by Gockel[5], in the Physikalisches Zeitschrift. They appear in fig. 52 for Kremmünster in the winter, and for Freiburg in the summer and the winter. While the observations are not sufficient in number to settle definitely the normal maxima and minima, yet they appear to indicate two crests in the forenoon, 8 a. m. and 10–11 a. m., and two in the evening, 8 p. m. and 10–11 p. m., with a fifth crest about 3 p. m., as is the case with the atmospheric electric potential.

There is yet another fact which can be brought out by comparing the annual numbers of the atmospheric electric potential at Greenwich with the well known variation of the annual prominence numbers, as given by me in the Monthly Weather Review for November, 1903. The Greenwich numbers are taken from the annual reports of that observatory, and are to be found in Table 9, "Variation of the atmospheric electric potential numbers on an arbitrary scale". For the years 1881-1888 the scale seems to be different from that of the years 1890-1901 in about the ratio of 1 to 2, and I have multiplied the first set by the factor 2 to give about the same amplitude for the entire series, because the location of the crests will not be altered. There are three columns, for "All days", "Rainy days", and "Clear days", respectively. These data are plotted in fig. 53, "Annual variation of the number of solar prominences and the atmospheric electric potential," but the potential curves are plotted in an inverse sense to that of the prominences. This implies that an increase in the solar activity, which produces the prominences, at the same time operates to reduce the normal atmospheric electric potential near the surface of the earth. The number and the location of the crests

[1] Des Variations de l'Électricité atmosphérique a Perpignan, par le Docteur Fines, 1890, Comptes Rendus.

[2] Étude de la variation diurne de l'Électricité atmosphérique, Par M. A.-B. Chauveau, 1902, Bureau Central, Paris.

[3] Greenwich Magnetical and Meteorological Observations.

[4] Phys. Zeit. 5, No. 10, p. 259.

[5] Potentialgefälle und elektrische Zerstreuung in der Atmosphäre. A. Gockel, Phys. Zeit. 4, No. 30, pp. 871–876; and 5, No. 10, pp. 257–259.

make this inference probable for these two elements. We have already shown in various places, summarized in the same paper, Monthly Weather Review, November, 1903, that the force of the deflecting magnetic vector s has a variation in its annual numbers which is in synchronism with that of the prominence curve. Hence, the magnetic field varies directly, while the electrostatic field varies inversely, to that of the solar energy, as shown by the frequency of the prominences, faculas, spots, coronas, and the intensity of the radiation generally.

I have brought together the several typical curves, such as emerge from an inspection of the charts and the figures of the preceding data, in fig. 54, Section I, "Comparison of the diurnal periods of temperature-fall, pressure, temperature, vapor tension, electric potential, and coefficient of dissipation". They are to be regarded as normal types of periodicity such as occur generally most vigorously during the summer months. The temperature-fall curve is from figs. 2-13, as for July; the semidiurnal pressure and temperature curves are from figs. 26-37, with some little change in the amplitudes; the vapor tension curves are from figs. 38-49, and are those for the 50, 195, and 400-meter levels in the midsummer; the electric potential gradient is from fig. 51, and the coefficient of dissipation is from fig. 52. It should be remembered that the relative values of the ordinates vary as follows:

An increase of the ordinate upward means—

(1) A greater temperature-fall, or lowering of temperature.
(2) An increase in the pressure.
(3) A decrease in the temperature.
(4) An increase in the vapor tension.
(5) An increase in the electric potential.
(6) An increase in the coefficient of dissipation.

From fig. 54, Section II, we learn that the double crests of the electric potential and coefficient of dissipation belong one to the temperature-falls at 8 a. m. and 8 p. m., and the other to the pressure-rises at 10-11 a. m. and 10-11 p. m., while the 3 p. m. crest seems to be associated with the reversal of these curves at the time of the two minima in the afternoon. The 8 a. m. and 8 p. m. temperature maxima occur in the midst of the most rapid temperature-rise in the forenoon, and the most rapid temperature-fall in the afternoon. The semidiurnal pressure curve lags about two hours behind the temperature effect, and it must be closely associated with the dynamic effect of rapidly rising and falling vertical convection currents. The exact process involved in this retardation is worth a special investigation. The vapor tension curve, also due to temperature action in producing vertical convection currents, lags yet farther behind the temperature cause, the retardation increasing from three hours at the surface to four or five hours at higher levels. It is pointed out that this physical convection in time between the vertical and horizontal coordinates affords a means of computing the vertical velocity of the heads of the effective waves of the several kinds. One must, however, take careful note of the circumstance that the entire system is being propagated from right to left on the diagram with a velocity proportional to the linear velocity of the earth's rotation at the latitude of the station. The night effect is overtaken by the advancing cone of the day temperature waves, and this makes the vertical retardation fall to the right in ascending from the base line of the abscissas.

From these considerations it is evident that we are dealing with a temperature effect throughout this series of phenomena, and that it is confined to the lower strata of the atmosphere, within two miles of the surface, because the diurnal variation of temperature is not efficient above that level. Hence, we must conclude that they are all consequences of the solar radiation, which, as is generally admitted, is the cause of the variation of the diurnal temperature by indirect action from the ground.

I have been thus careful to explain that we are concerned simply with the lower strata of the atmosphere, and have nothing to do with the higher strata, because in the following paper I shall be able to show that the diurnal variation of the magnetic field is also a temperature effect in the lower strata of the atmosphere. We may now make some further remarks on the physical cause of the atmospheric electricity of the earth's gaseous envelope.

THE CAUSE OF THE ELECTRICITY IN THE EARTH'S ATMOSPHERE.

A brief account of some of the relations between the ionization and electric potential of the atmosphere can be found in the 4th chapter of my report on "Eclipse Meteorology" Weather Bureau, Bulletin I, 1902; see also the report by M. A. B. Chauveau, already referred to, and several papers by H. Ebert, Elster and Geitel, P. Lenard, C. Barus, and others, containing the views which have been advanced recently to account for this elusive phenomenon. It is conceded that + ions and — ions are normal constituents of the atmosphere, and that their generation and recombination, with the attendant motions of their electric charges, form the basis of this physical process. These ions are produced in very many ways in the temporary disintegration of the dynamic structures of the molecules and atoms, by which they are temporarily detached and move about in search of new places of neutralization. The most prolific source of their formation is probably the action of the short waves of the solar radiation upon the aqueous vapor of the atmosphere, whether visibly condensed or in the invisible state. There is, also, a further source of the ions in the action of the electromagnetic field of the sun operating upon the electric and the magnetic fields of the earth within the gaseous materials of the atmosphere. The complexity of the physical process is very great, and I shall confine my attention more to the modes of redistribution of the ions found in the air, and moving as currents of electricity, than to their original formation. Electric potential gradients are due to a separation of the positive and the negative charges, and ultimately the source of this energy will go back to some transformation of gravitational force. At present, the inquiry culminates in the necessity of accounting for the negative charge of the earth, which is doubtless a very difficult problem. I shall make the following suggestions regarding it.

THE NEGATIVE CHARGE OF THE EARTH.

Elster and Geitel's theory of the atmospheric electric potential assumes that the negative ions when produced in the atmosphere move to the earth, which is a conducting body, more rapidly than the positive ions, and that their accumulation upon it produces the observed charge. This surface charge, it is inferred from Linss's experiments, now verified, dissipates at the rate of discharging itself, on the average, in 100 minutes. But the researches of Simpson (Phil. Mag. 6, 589, 1903) Ebert and Ewers (Phys. Zeits. 5, No. 5, p. 135-140) throw doubt upon this view, because they have not been able to show that a conductor in ionized air receives any charge by the absorption of either kind of the ions surrounding it. Ebert, on the other hand, seeks to supply the surface charge of the earth by referring the source to radio-active constituents within the earth, which, discharging through the porous ground by the capillary action of the narrow channels, deposits the negative charges on the sides, while the positive charges are ejected. It is not clear that this process is applicable to the great oceanic areas of the earth, though these show about the same electrical gradients as the land areas, nor would this process appear to allow the negative ion contents to accumulate sufficiently in the strata of the air at some distance above the ground, to produce the high tension observed in lightning discharges and in nondisruptive strains.

There are, however, several other processes which probably contribute to the separation of the positive and negative ions,

by which the former tend to accumulate in the atmosphere and the latter at the surface of the earth.

(1) The different masses of the + ions and the — ions, the + ions being much larger than the — ions, may have a differential relation to the mechanical light pressure due to electromagnetic radiation, and it is possible that the negative charges are driven before it, within the earth's atmosphere itself, more abundantly than the positive charges. If the incoming solar radiation produces + ions and — ions excessively upon impact with the top of the aqueous vapor arch, which is near the surface of the earth in the polar zones and high above the ground in the Tropics, then the — ions may be driven to the earth by the mechanical pressure of the light, while the + ions tend to remain in the higher strata. Although this is not quite parallel to the case of the formation of cathode streams in rarefied gases or the comet tails in free space, there may be some differential action of this kind that tends to separate these two kinds of ions, carrying the negative ions to the earth.

(2) Since fresh ions are produced in some way by the radiation in the existing electrostatic field, V, surrounding the earth, therefore the velocity of the motion of the nucleus carrying the charge, e, where the radius of the nucleus is R and the viscosity of the air is μ, is determined by C. Barus from the formula,

$$v = \frac{Ve}{4\pi\mu R}. \quad \text{(Science, January 2, 1903.)}$$

For $R = 10^{-6}$, $\mu = 0.0002$, $e = 200 \times 7 \times 10^{-10}$ *E. S. U.*, $v = 37$ cm/sec = 0.8 mile per hour, for the unit electrostatic field = 0.003 mile per hour for a field of 1 volt/cm. Hence, by changing the sign of e, the ion charge in the formula, those of one sign would be driven in one direction and those of the other sign in the opposite direction. This is evidently one true cause of the observed separation.

(3) Similarly, the + ions and the — ions, being generated in the free air by radiation in the midst of the magnetic field surrounding the earth, should be driven in opposite directions along the lines of force to the polar regions. As the electrostatic field tends to separate a swarm of + ions and — ions in radial directions, the + ions to higher strata and the — ions to earth, so the magnetic field tends to send + ions to one polar region and the — ions to the opposite polar region. In fact, these electric and magnetic lines of force are the natural highways of travel for the ion content of the air, and, in a word, it is my opinion that the ions are generally moving about from one place to another while they are free from the bonds of atomic and molecular combination. Of course the temperature, vapor content, and pressure may accelerate or impede these movements, as has already been pointed out by Elster and Geitel, Ebert, Gockel, and others, and so introduce the meteorological conditions which have been observed. The ions in this way become sensitive registers of the physical variation in the atmosphere, and have much interest to the meteorologist.

(4) There is yet one more cause for the earth's electric surface charge which may be the most important of all, and that exists inside the earth in the atomic circulation within its mass. W. Sutherland[6] has indicated that the static electric charge of the earth, and its magnetic field may be due to a slight displacement of the positive and the negative body charges, through a distance comparable to the diameter of a molecule, 10^{-8}cm., whereby the negative charge of the earth, as a whole, is that distance farther from the center than the positive charge. There seems to be much difficulty in understanding how this takes place physically in the earth, which should apparently be electrically conducting under high temperature and pressure, but it may be possible to escape from this criticism by resorting to the following modified conception of a dynamic rather than a static character.

It seems to be probable that atoms of matter are constituted of negative ions circulating rapidly, in connection with a larger, more inert positive charge, either inside or outside of it. The velocity of rotation of the — ions is greater than the + ions and this would imply that there is a tendency for some of the negative ions to pursue paths of larger radii than the positive ions, and also at greater angular velocity. Thus, they ought, in one way or another, to recede farther from the center of the earth than the positive ions, but in so far as their natural orbital motions are impeded they will tend to accumulate and become static charges nearer the surface of the earth. If these circulating ions, the negative ions moving more vigorously, have a tendency to become polarized as to their orbit, that is to circulate in planes perpendicular to the axis of the rotation of the earth, through the effect of the earth's deflecting force due to its own angular velocity, then, there should be integrated a resultant true magnetic field directed from north to south through the interior of the earth. It is quite likely that Southerland's view can be modified from the electrostatic basis proposed by him to this electrodynamic basis, with resulting static negative residual charge at the earth's surface, and magnetic field within the earth, sustaining that observed outside of its surface. Should this be the case, it must be inferred that similar processes go on in the sun and the stars, and that all large rotating celestial bodies are polarized magnetic spheres, with electrostatic charged surfaces. The variation of the distribution of these charges from time to time, and from region to region, constitute the source of the periodic and aperiodic disturbances with which we are becoming familiar in several different classes of observations. To whatever extent these processes are in operation within the earth, and in its atmosphere, as here outlined, and thus cause the observed general distribution of the positive electric charge in the higher strata, with the negative charge at the surface of the earth, we may properly consider the variation of the electric gradients in the atmosphere as a phenomenon resulting therefrom, in consequence of changes in the temperature conditions in the earth and in the atmosphere.

THE PERIODIC VARIATIONS OF THE ELECTRIC POTENTIAL GRADIENT IN THE EARTH'S ATMOSPHERE.

I have called attention to the fact that the electric potential gradient varies from year to year inversely to the solar prominence numbers, and, in consequence, inversely to the strength of the solar radiation, insolation, and terrestrial temperatures. An increase of the temperature of the lower atmosphere decreases the potential tension between the masses of the positive and of the negative ions. Similarly the potential gradient is greater in the polar regions of the earth where the air is cold, than at the equator where it is warm. At any given station the gradient is greater in winter than in summer. Generally, cooling the air is favorable to producing an increase of the electrical gradient. Likewise, it will be seen by referring to figs. 26–37, 50, 52, 53, 54 that the diurnal maxima of the electric potential occur at the times of the true minima of the temperature waves, 8 a. m., 8. p. m., or as modified by the correlative pressure maximum waves occurring two hours later, 10 a. m., 10 p. m. We may, therefore, conclude that one uniform physical process is concerned throughout this series of electrical gradient transformations, namely, *the air is cooled in some way whenever there is an increase of the electrical gradient.*

(5) It seems to me but a step to arrive at an equally general and valid theory of the variation of the electric potential. We need only admit that the positive ions have a stronger affinity for a gas at low temperature than for the same gas at a higher temperature. If the + ions seek regions of low temperature and the — ions move to the regions of high temperature, we have yet another cause, in addition to the four already men-

[6] A possible cause of the earth's magnetism, Terr. Mag. June, 1900. June, 1903. December, 1904. W. Sutherland.

tioned for the separation of the positive and the negative ions into two masses. Hence, in the diurnal waves of temperature the positive ions flow downward from their normal level to a lower level as the minimum of the temperature wave in the lower strata passes over the place. This implies that at the 8 a. m. and 8 p. m., local hours, a stream of + ions is directed downward, so that the positive ions as a mass approach more nearly the surface of the earth where the negative ions are already accumulated. Hence, the potential gradient of electricity will be increased in proportion to this approach. It seems that the negative stratum may be considered as quite steady in elevation, while the positive stratum rises and falls in a wave, synchronously with the passage of the temperature wave. Referring to Section III, fig. 54, the temperature curve of Section I has been plotted once more in the reverse position, to show the approach of this cold stratum to the earth. From this exposition of the facts, I assume that a current of + ions descends at 8 a. m. and 8 p. m. with the temperature wave, and that the same ions ascend at 3 a. m. and 3 p. m., while the − ions remain all the while at about the same level. This, evidently, causes the observed increase and decrease of the electric potential as observed at the surface during the 24 hours of the day. I see in the movement of the + ions from one elevation to another, while the − ions remain on or near the charged surface of the earth, the true cause of the diurnal variations of the atmospheric electric potential gradient.

TABLE 3.—*Diurnal variation of the vapor tension at Parc St. Maur, Paris.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12 a.	− .10	0.0	+ .08	+ .23	+ .17	+ .18	+ .14	+ .16	− .02	− .19	− .17	− .02
1	− .08	− 0.5	+ .01	+ .16	+ .03	− .01	+ .08	+ .16	− .09	− .18	− .16	− .07
2	......	......	......	......	......	......	......	......	......	......	......	......
3	......	......	..	......	......	......	......	......	......	......	......	......
4	− .14	− .09	− .08	+ .03	− .16	− .23	− .18	− .08	− .45	− .42	− .18	− .18
5	− .18	− .13	− .15	− .02	− .19	− .26	− .23	− .15	− .55	− .49	− .34	− .22
6	− .17	− .18	− .18	− .07	.00	− .07	− .01	.00	− .56	− .56	− .37	− .20
7	− .21	− .21	− .11	+ .22	+ .22	+ .12	+ .21	+ .27	− .25	− .53	− .37	− .21
8	− .17	− .17	− .01	+ .30	+ .25	+ .26	+ .34	+ .43	+ .14	− .24	− .29	− .22
9	− .12	− .07	+ .09	+ .24	+ .18	+ .24	+ .38	+ .44	+ .38	+ .12	− .10	− .13
10	− .01	+ .01	+ .12	+ .09	+ .04	+ .10	+ .32	+ .27	+ .42	+ .28	+ .07	− .01
11	+ .05	+ .06	+ .09	− .12	− .10	− .10	+ .09	+ .02	+ .19	+ .33	+ .22	+ .08
12 p	+ .10	+ .06	+ .03	− .20	− .15	− .30	− .18	− .24	+ .04	+ .22	+ .24	+ .09
1	+ .13	+ .06	− .04	− .26	− .30	− .29	− .28	− .24	− .14	+ .25	+ .28	+ .09
2	+ .13	+ .06	− .11	− .35	− .26	− .32	− .33	− .57	− .22	+ .24	+ .24	+ .15
3	+ .18	+ .05	− .13	− .37	− .36	− .35	− .43	− .63	− .33	+ .25	+ .27	+ .20
4	+ .19	+ .08	− .14	− .41	− .39	− .27	− .43	− .64	− .15	+ .27	+ .34	+ .22
5	+ .21	+ .12	− .10	− .40	− .33	− .08	− .34	− .48	+ .11	+ .29	+ .29	+ .15
6	+ .18	+ .09	+ .01	− .22	− .22	− .10	− .26	− .14	+ .32	+ .40	+ .17	+ .14
7	+ .12	+ .13	+ .09	+ .01	+ .12	+ .24	+ .09	+ .18	+ .38	+ .29	+ .10	+ .13
8	+ .07	+ .10	+ .13	+ .16	+ .24	+ .39	+ .31	+ .24	+ .33	+ .19	+ .07	+ .08
9	+ .03	+ .10	+ .12	+ .24	+ .29	+ .39	+ .25	+ .27	+ .27	+ .11	+ .02	+ .06
10	− .05	+ .04	+ .09	+ .25	+ .47	+ .32	+ .21	+ .24	+ .18	+ .01	− .05	.00
11	− .08	+ .01	+ .08	+ .21	+ .20	+ .24	+ .17	+ .22	+ .11	− .08	− .07	− .02
12	− .10	.00	+ .08	+ .23	+ .17	+ .18	+ .14	+ .16	− .02	− .19	− .17	− .02
Means	5.33	5.21	5.15	6.07	7.59	10.10	11.44	11.20	9.99	7.99	6.29	5.43

TABLE 4.—*Diurnal variation of the vapor tension at Blue Hill, 195-meter level.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12 a	+ .85	+ .71	+ .75	+1.14	+ .92	+1.12	+ .75	+ .95	+ .40	+ .69	+ .50	+ .45
1	+ .72	+ .62	+ .67	+ .91	+ .87	+ .80	+ .56	+ .40	+ .39	+ .39	+ .48	+ .45
2	+ .49	+ .52	+ .47	+ .75	+ .78	+ .13	+ .55	− .10	+ .11	+ .22	+ .42	+ .43
3	+ .33	+ .36	+ .33	+ .47	+ .65	− .04	+ .24	− .30	− .17	+ .05	+ .31	+ .34
4	+ .14	+ .26	+ .21	+ .21	+ .19	− .11	+ .10	− .43	− .44	− .06	+ .11	+ .27
5	+ .04	+ .06	+ .03	+ .15	− .08	− .16	− .01	− .49	− .71	− .24	− .03	+ .12
6	− .08	− .10	− .10	− .06	− .33	− .47	− .21	− .74	− .94	− .43	− .16	.00
7	− .25	− .21	− .30	− .11	− .57	− .50	− .41	− .46	−1.07	− .60	− .36	− .10
8	− .31	− .35	− .37	− .29	− .46	− .24	− .57	− .56	− .93	− .59	− .45	− .19
9	− .43	− .47	− .56	− .23	− .46	− .31	− .69	− .41	− .49	− .52	− .42	− .23
10	− .46	− .51	− .57	− .32	− .37	+ .05	− .34	− .02	+ .03	− .40	− .27	− .28
11	− .52	− .49	− .59	− .29	− .39	− .14	− .11	+ .28	+ .26	− .13	− .12	− .22
12 p	− .51	− .54	− .56	− .38	− .33	+ .22	+ .41	+ .59	+ .46	− .10	− .04	− .28
1	− .50	− .48	− .56	− .46	− .37	− .29	+ .37	+ .53	+ .55	+ .03	− .01	− .33
2	− .49	− .43	− .46	− .65	− .43	− .01	+ .28	+ .68	− .55	+ .03	− .07	− .30
3	− .49	− .34	− .41	− .67	− .35	− .08	− .11	+ .22	+ .33	+ .09	− .17	− .30
4	− .47	− .27	− .20	− .60	− .37	− .25	− .20	+ .19	+ .11	− .01	− .34	− .29
5	− .38	− .22	− .14	− .58	− .83	− .46	− .45	− .16	+ .06	− .02	− .24	− .25
6	− .23	− .19	− .09	− .66	− .42	− .24	− .66	− .17	+ .17	− .04	− .28	− .20
7	− .12	− .06	− .01	− .48	− .37	− .41	− .63	− .48	+ .11	− .06	− .28	− .17
8	+ .04	− .03	+ .09	− .39	− .05	− .45	− .55	− .26	− .08	− .03	− .21	− .12
9	+ .34	+ .22	+ .32	+ .06	− .02	− .10	+ .05	− .10	+ .17	+ .10	− .10	+ .06
10	+ .54	+ .47	+ .60	+ .46	+ .41	+ .33	+ .12	+ .05	+ .26	+ .34	+ .04	+ .18
11	+ .79	+ .58	+ .65	+ .87	+ .79	+ .52	+ .79	+ .60	+ .34	+ .46	+ .16	+ .37
12	+ .85	+ .71	+ .75	+1.14	+ .92	+1.12	+ .75	+ .95	+ .40	+ .69	+ .50	+ .45
Means	2.06	2.13	2.63	3.78	6.39	9.49	12.37	11.76	8.69	4.76	3.29	2.16

TABLE 5.—*Diurnal variation of the vapor tension at Blue Hill, 400-meter level.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12 a	+ .13	+ .06	+ .01	− .09	+ .10	− .46	− .11	− .19	+ .20	+ .22	+ .12	+ .13
1	+ .14	.00	− .02	− .15	+ .13	− .51	− .48	− .30	+ .31	+ .29	+ .18	+ .16
2	+ .13	− .06	− .03	− .21	+ .17	− .59	− .74	− .53	+ .31	+ .31	+ .23	+ .17
3	+ .09	− .10	− .06	− .25	+ .13	− .64	−1.01	− .70	+ .26	+ .31	+ .25	+ .17
4	− .01	− .14	− .08	− .31	+ .10	− .73	−1.11	− .82	+ .09	+ .34	+ .25	+ .16
5	− .12	− .17	− .11	− .31	− .12	− .73	−1.11	− .93	− .07	+ .09	+ .13	+ .07
6	− .19	− .19	− .15	− .31	− .32	− .73	−1.08	− .82	− .23	− .06	− .12	− .01
7	− .22	− .20	− .19	− .29	− .55	− .64	−1.01	− .70	− .45	− .18	− .19	− .10
8	− .22	− .22	− .21	− .22	− .64	− .46	− .74	− .53	− .49	− .29	− .23	− .15
9	− .20	− .20	− .17	− .15	− .65	− .28	− .52	− .36	− .49	− .29	− .21	− .16
10	− .15	− .15	− .10	− .03	− .48	− .05	− .30	+ .01	− .28	− .24	− .12	− .16
11	− .06	− .03	− .02	+ .10	− .15	+ .29	− .05	+ .26	− .01	− .09	− .07	− .16
12 p	+ .06	+ .11	+ .11	+ .27	+ .10	+ .59	+ .27	+ .48	+ .43	+ .03	− .02	− .15
1	+ .13	+ .17	+ .20	+ .47	+ .35	+ .95	+ .48	+1.01	+ .48	+ .12	− .02	− .15
2	+ .15	+ .21	+ .24	+ .56	+ .51	+1.11	+ .74	+1.29	+ .54	+ .12	− .04	− .14
3	+ .09	+ .21	+ .25	+ .63	+ .58	+1.44	+ .89	+1.47	+ .51	+ .09	− .08	− .12
4	+ .13	+ .22	+ .27	+ .53	+ .51	+1.49	+1.00	+1.24	+ .41	+ .03	− .12	− .10
5	+ .08	+ .20	+ .24	+ .34	+ .35	+1.16	+1.07	+ .80	+ .22	− .09	− .12	− .07
6	+ .03	+ .14	+ .17	+ .25	+ .17	+ .64	+1.00	+ .42	− .12	− .18	− .12	− .02
7	− .02	+ .08	+ .09	− .05	+ .03	+ .09	+ .94	+ .11	− .33	− .29	− .10	+ .02
8	− .05	+ .05	+ .01	− .11	− .12	− .19	+ .74	− .19	− .49	− .29	− .02	+ .07
9	− .05	+ .01	− .04	− .15	− .12	− .37	+ .50	− .30	− .49	− .26	+ .04	+ .09
10	− .03	+ .02	− .06	− .15	− .12	− .41	+ .22	− .30	− .49	− .09	+ .13	+ .11
11	+ .04	+ .03	− .04	− .13	− .12	− .54	− .05	− .30	− .17	+ .12	+ .12	+ .14
12	+ .13	+ .06	+ .01	− .09	+ .10	− .46	− .11	− .19	+ .20	+ .22	+ .12	+ .13
Means	1.59	1.57	1.74	3.02	5.40	7.43	10.10	9.57	8.32	4.45	3.14	1.90

TABLE 6.—*Diurnal variation of the vapor tension at Blue Hill, 1000-meter level.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12 a	+ .21	+ .12	+ .16	+ .06	+ .09	− .31	− .15	+ .21	+ .26	+ .34	.00	+ .22
1	+ .17	+ .11	+ .08	− .05	− .16	− .68	− .49	− .24	+ .17	+ .27	− .03	+ .20
2	+ .08	+ .07	+ .00	− .15	− .42	− .96	− .64	− .84	− .03	+ .10	− .16	+ .07
3	+ .03	+ .01	− .08	− .22	− .53	−1.22	−1.39	−1.28	− .31	− .09	− .30	− .06
4	− .09	− .04	− .09	− .26	− .67	−1.32	−1.64	−1.56	− .62	− .27	− .33	− .11
5	− .14	− .07	− .09	− .24	− .80	−1.32	−2.00	−1.60	− .87	− .42	− .44	− .17
6	− .17	− .09	− .03	− .20	− .74	−1.19	−1.84	−1.49	− .94	− .37	− .44	− .21
7	− .22	− .07	− .02	− .14	− .72	− .96	−1.55	−1.27	− .88	− .36	− .44	− .29
8	− .20	− .05	− .05	− .09	− .58	− .62	−1.29	− .90	− .78	− .36	− .29	− .26
9	− .16	− .07	− .09	− .10	− .43	− .27	− .95	− .53	− .48	− .27	− .13	− .20
10	− .15	− .07	− .10	− .06	− .09	+ .04	− .37	− .10	− .18	− .21	+ .04	− .14
11	− .15	− .08	− .15	+ .02	+ .04	+ .44	+ .06	+ .28	+ .14	− .08	+ .10	− .09
12 p	− .16	− .09	− .16	+ .07	+ .20	+ .61	+ .49	+ .63	+ .46	+ .06	+ .19	− .05
1	− .14	− .09	− .10	+ .07	+ .38	+ .94	+ .74	+1.01	+ .55	+ .22	+ .34	− .05
2	− .14	− .07	− .05	+ .06	+ .52	+1.21	+1.26	+1.22	+ .95	+ .22	+ .32	− .03
3	− .11	− .01	− .01	+ .07	+ .51	+1.28	+1.51	+1.34	+ .95	+ .18	+ .32	+ .01
4	− .09	− .01	+ .03	+ .13	+ .61	+1.37	+1.64	+1.21	+1.05	+ .12	+ .28	+ .02
5	− .01	− .02	+ .02	+ .17	+ .57	+1.24	+1.70	+1.09	+ .65	+ .03	+ .20	+ .05
6	+ .09	− .01	+ .03	+ .14	+ .51	+1.05	+1.70	+ .85	+ .56	+ .03	+ .15	+ .06
7	+ .19	+ .01	+ .01	+ .12	+ .43	+ .71	+1.64	+ .55	+ .43	.00	+ .10	+ .11
8	+ .23	+ .05	+ .06	+ .14	+ .37	+ .43	+1.29	+ .38	+ .20	− .03	+ .10	+ .17
9	+ .24	+ .06	+ .13	+ .10	+ .37	+ .08	+ .91	+ .21	+ .10	+ .06	+ .08	+ .19
10	+ .23	+ .11	+ .17	+ .13	+ .37	+ .04	+ .53	+ .02	+ .24	+ .19	+ .08	+ .21
11	+ .24	+ .14	+ .18	+ .13	+ .23	− .27	+ .09	+ .09	+ .23	+ .35	+ .05	+ .22
12	+ .21	+ .12	+ .16	+ .06	+ .09	− .31	− .15	+ .21	+ .26	+ .34	.00	+ .22
Means	1.37	1.32	1.73	2.82	4.66	5.94	8.73	8.15	6.42	4.37	2.91	1.82

TABLE 7.—*Diurnal variation of the atmospheric electric potential, Greenwich observations, on an arbitrary scale. Clear days.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12 a	− 1	− 4	+ 4	+ 6	+ 4	+ 6	+ 5	+ 6	0	− 1	− 2	+ 2
1	− 7	− 7	− 1	+ 2	0	+ 3	+ 8	+ 3	− 5	− 4	− 7	− 2
2	− 9	−12	− 7	− 1	− 3	+ 2	+ 1	+ 1	−10	− 7	− 6	− 6
3	−11	−14	− 9	− 4	− 6	0	− 2	− 2	−11	− 9	− 8	−11
4	−12	−14	− 9	− 5	− 8	− 2	− 3	− 4	−11	−10	− 8	−14
5	−14	−13	− 7	− 2	− 7	− 2	− 1	− 4	−14	−12	− 8	−14
6	−14	−12	− 4	+ 2	− 2	0	+ 3	− 1	−13	−12	− 6	−12
7	− 9	− 6	0	+ 9	+ 7	+ 4	+ 4	+ 1	−10	−12	− 3	− 9
8	− 6	− 4	+ 2	+11	+10	+ 1	+ 1	+ 1	− 7	−13	− 1	− 7
9	− 2	− 1	+ 2	+ 5	+ 3	− 2	+ 1	0	− 2	− 7	0	− 3
10	+ 6	+ 8	+ 6	+ 1	+10	+ 3	+ 7	+ 6	+ 8	+ 1	+ 9	+ 2
11	+10	+ 7	+ 4	− 3	+ 4	− 2	+ 3	+ 3	+ 9	+ 5	+ 5	+ 9
12 p	+ 4	+ 1	− 2	− 9	− 6	− 5	− 3	− 2	+ 4	0	+ 3	+ 6
1	+ 4	− 2	− 5	−11	− 8	− 8	− 7	− 5	+ 1	+ 2	+ 2	+ 7
2	+ 4	− 1	− 7	−10	− 9	− 9	−10	− 8	− 1	+ 2	+ 2	+ 6
3	+ 6	+ 2	− 8	−10	− 9	− 9	− 8	− 8	− 1	+ 4	+ 3	+ 5
4	+ 7	+ 6	−10	− 9	− 5	− 9	− 6	− 8	+ 1	+ 9	+ 4	+ 5
5	+ 7	+ 8	− 3	− 6	− 1	− 6	− 5	− 7	+ 7	+14	+ 6	+ 6
6	+ 8	+10	+ 2	− 3	+ 1	− 4	− 3	− 2	+11	+14	+ 6	+ 7
7	+ 7	+12	+ 8	0	0	− 3	− 2	+ 2	+13	+11	+ 4	+ 5
8	+ 7	+10	+11	+ 5	+ 1	− 1	− 1	+ 4	+12	+ 7	+ 3	+ 4
9	+ 6	+ 7	+10	+ 7	+ 7	+ 6	+ 5	+ 8	+ 9	+ 7	+ 4	+ 9
10	+ 5	+ 7	+10	+ 9	+10	+11	+ 9	+10	+ 6	+ 8	+ 5	+ 9
11	+ 2	+ 3	+ 5	+ 5	+ 6	+10	+ 7	+ 6	+ 3	+ 4	+ 2	+ 6
12	− 5	− 3	− 2	− 1	+ 2	+ 6	+ 4	+ 2	− 4	+ 1	− 2	+ 2
Means	76	84	73	66	60	42	44	45	49	56	49	71

TABLE 8.—*Diurnal variation of the atmospheric electric potential; Greenwich observations; rainy and clear days.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12a.	0	− 2	+ 1	+ 4	+ 5	+ 7	+ 5	+ 6	− 4	− 1	0	+ 3
1	− 7	− 3	− 2	+ 3	+ 2	+ 5	+ 3	+ 3	− 3	− 5	− 3	− 3
2	− 9	− 9	− 5	− 3	− 3	0	− 1	+ 3	− 6	− 6	− 4	−10
3	−11	−10	− 8	− 5	− 7	− 1	− 4	− 1	− 9	− 8	− 7	−13
4	−14	−12	− 8	− 6	− 9	− 4	− 5	− 3	−10	−10	− 7	−14
5	−13	−12	− 6	− 7	− 8	− 3	− 2	− 3	−12	−11	− 7	−14
6	−14	−10	− 3	− 5	− 5	− 1	− 1	− 2	−12	−12	− 7	−12
7	−10	− 6	+ 2	+ 2	+ 4	+ 1	+ 2	0	− 9	− 8	− 5	− 6
8	− 8	− 4	+ 6	+ 6	+ 6	− 1	+ 2	0	− 6	− 7	− 4	− 2
9	− 5	0	+ 2	+ 1	+ 4	− 3	+ 1	− 1	− 1	− 2	− 3	+ 1
10	+ 5	+ 6	+ 6	− 2	+ 4	+ 4	+ 9	+ 6	+ 6	+ 4	+ 2	+ 6
11	+ 8	+ 9	+ 2	− 2	+ 2	− 2	+ 5	+ 8	+ 7	+ 3	+ 3	+ 6
12p.	+ 4	+ 1	0	− 6	− 6	− 2	0	+ 1	+ 2	− 1	+ 2	+ 4
1	+ 6	0	0	− 5	− 8	− 6	− 6	− 7	+ 1	0	+ 1	+ 1
2	+ 5	− 1	− 3	− 2	−10	− 8	− 9	− 6	− 1	0	+ 1	+ 2
3	+ 6	+ 2	− 2	− 4	− 6	− 3	− 8	−12	− 1	+ 2	+ 3	+ 2
4	+ 8	+ 8	− 4	− 4	− 2	− 4	− 6	− 6	+ 1	+ 9	+ 3	+ 4
5	+ 5	+ 7	+ 2	− 3	+ 1	− 4	− 7	− 5	+ 5	+10	+ 3	+ 7
6	+ 8	+ 9	+ 7	+ 1	+ 1	− 2	− 1	+ 2	+ 9	+12	+ 4	+ 8
7	+10	+ 9	+ 8	+ 7	+ 6	+ 1	− 2	+ 3	+10	+ 9	+ 5	+ 7
8	+ 6	+ 7	+ 5	+ 9	+ 8	+ 3	− 2	+ 4	+ 8	+ 5	+ 4	+ 2
9	+ 4	+ 6	+ 6	+ 6	+ 9	+ 6	+ 6	+ 7	+ 6	+ 5	+ 3	+ 9
10	+ 5	+ 6	+ 5	+11	+12	+10	+10	+13	+ 6	+ 7	+ 4	+ 8
11	+ 4	+ 3	+ 2	+10	+11	+ 9	+ 9	+ 9	+ 3	+ 5	+ 2	+ 3
12	+ 1	− 8	− 1	+ 4	+ 5	+ 6	+ 8	+ 5	0	− 2	− 2	+ 2
Means...	62	68	62	56	52	37	42	39	44	47	43	53

TABLE 9.—*Annual variation of the atmospheric electric potential; Greenwich observations; on an arbitrary scale.*

Years.	All days.	Rainy days.	Clear days.	Factor.	All days.	Rainy days.	Clear days.
1881	262	....	....	× 2 =	524	....	....
1882	210	121	287		420	242	574
1883	264	152	340		528	304	680
1884	236	117	299		472	234	598
1885	234	85	328		468	170	656
1886	224	127	301		448	254	602
1887	305	176	388		610	352	776
1888	285	169	370		570	338	740
1889	....	....	....	....	....	....	....
1890	....	....	....	....	629	433	725
1891	....	....	....	....	542	376	670
1892	....	....	....	....	465	332	557
1893	....	....	....	....	553	421	663
1894	....	....	....	....	514	358	661
1895	....	....	....	....	761	623	880
1896	....	....	....	....	661	516	768
1897	....	....	....	....	586	459	679
1898	....	....	....	....	483	342	553
1899	....	....	....	....	343	184	432
1900	....	....	....	....	450	338	539
1901	....	....	....	....	593	417	680

In my next paper I will show that this action, at the same time, produces the diurnal variation of the magnetic field as observed at the surface of the earth.

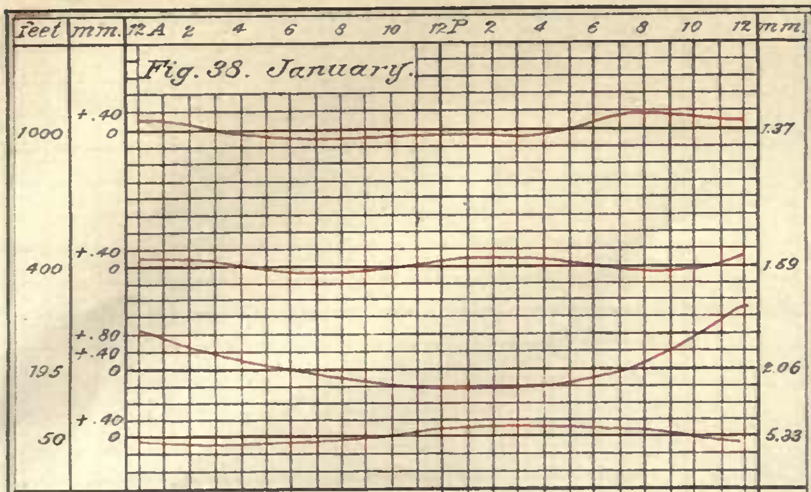


Fig. 38. January.

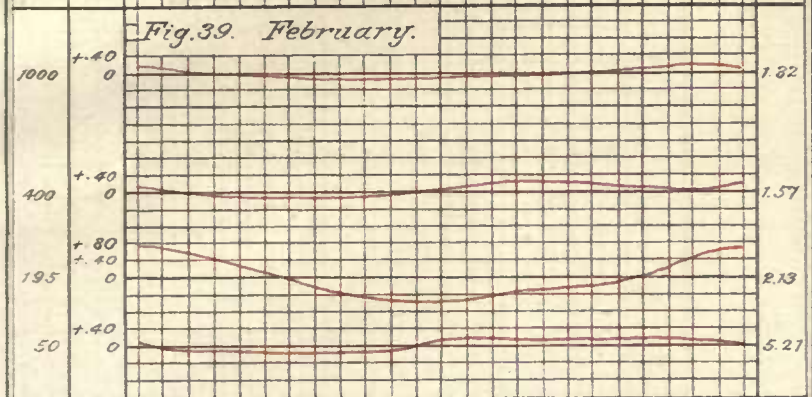


Fig. 39. February.

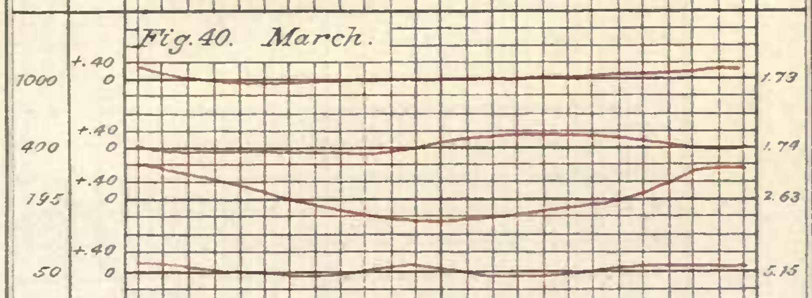


Fig. 40. March.

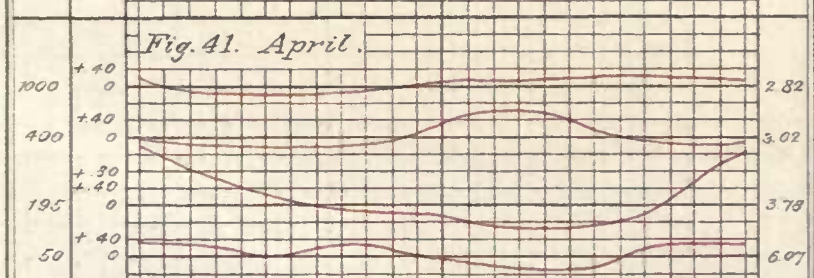


Fig. 41. April.

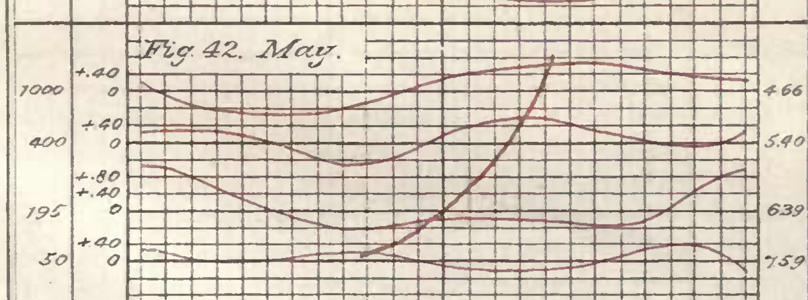


Fig. 42. May.

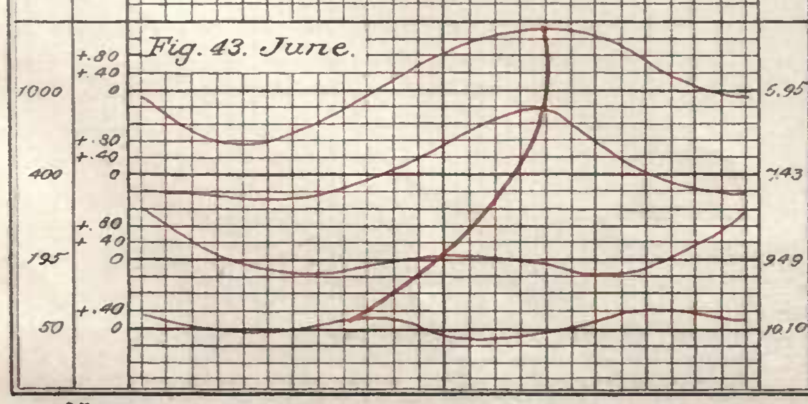


Fig. 43. June.

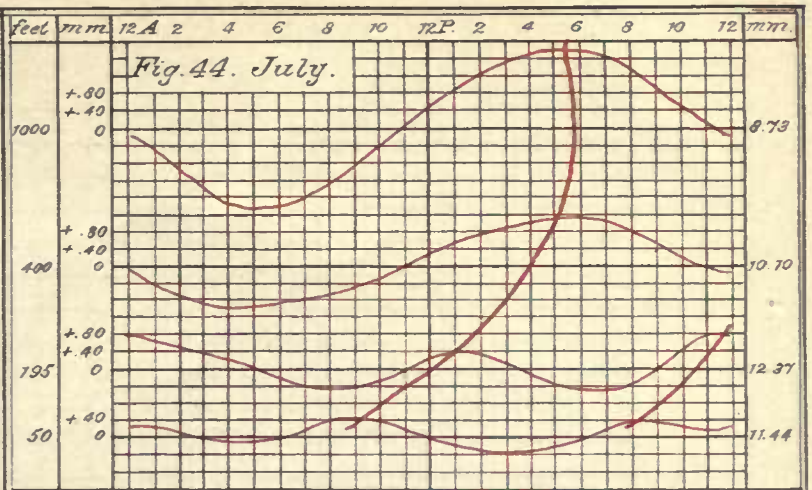


Fig. 44. July.

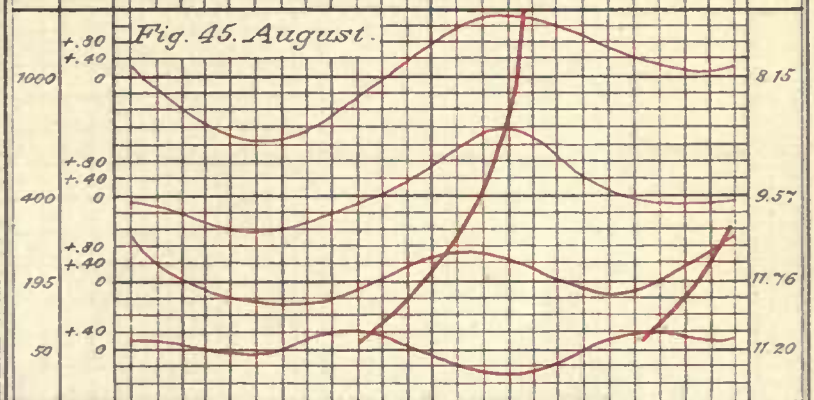


Fig. 45. August.

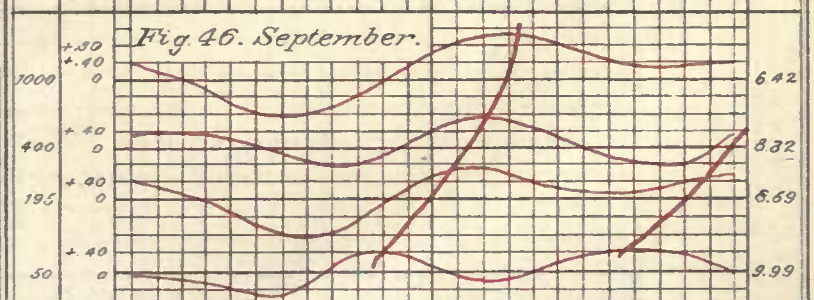


Fig. 46. September.

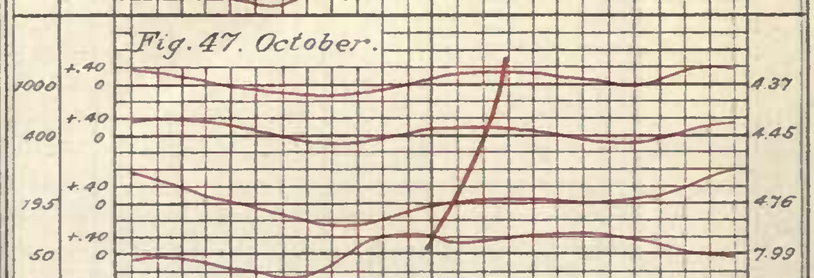


Fig. 47. October.

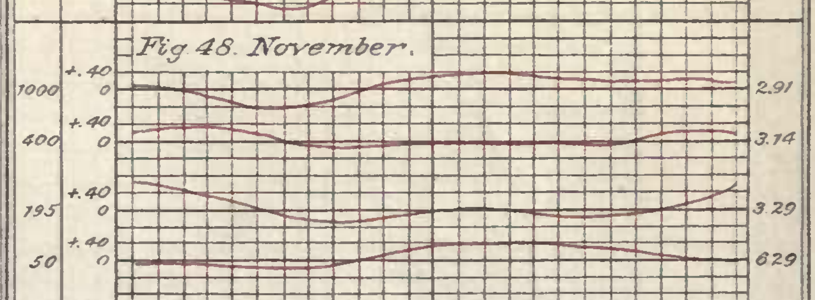


Fig. 48. November.

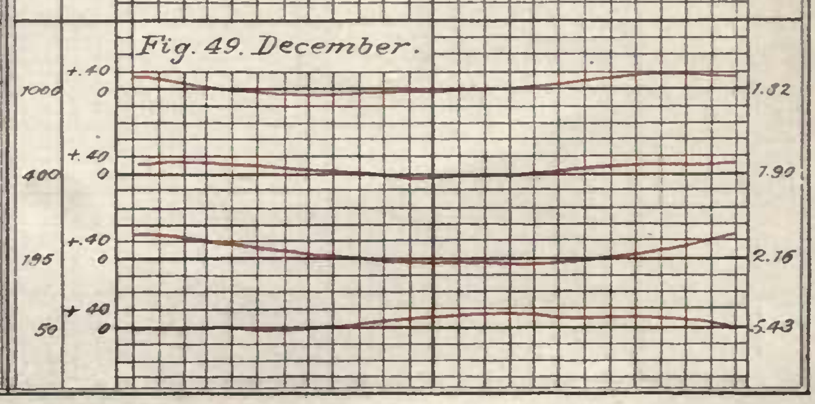


Fig. 49. December.

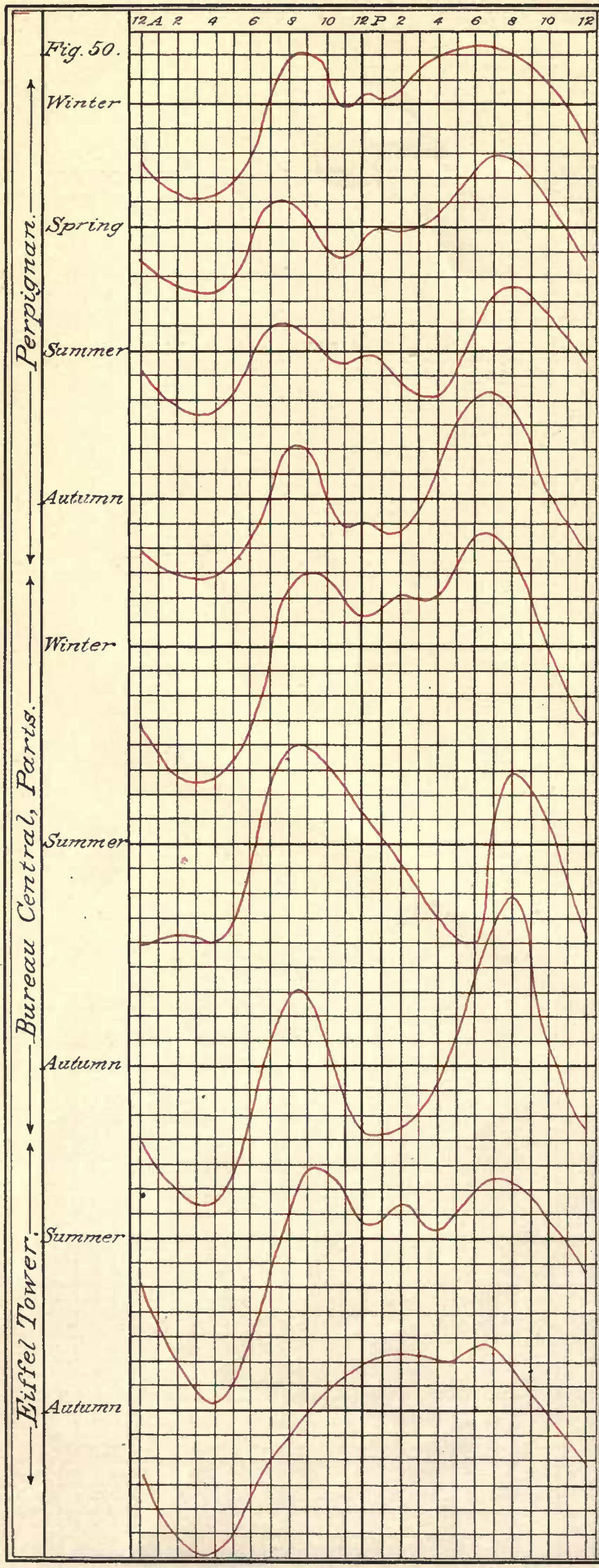


Fig. 50.
12A 2 4 6 8 10 12P 2 4 6 8 10 12
Winter
Spring
Summer
Autumn
Winter
Summer
Autumn
Summer
Autumn
Perpignan.
Bureau Central, Paris.
Eiffel Tower.

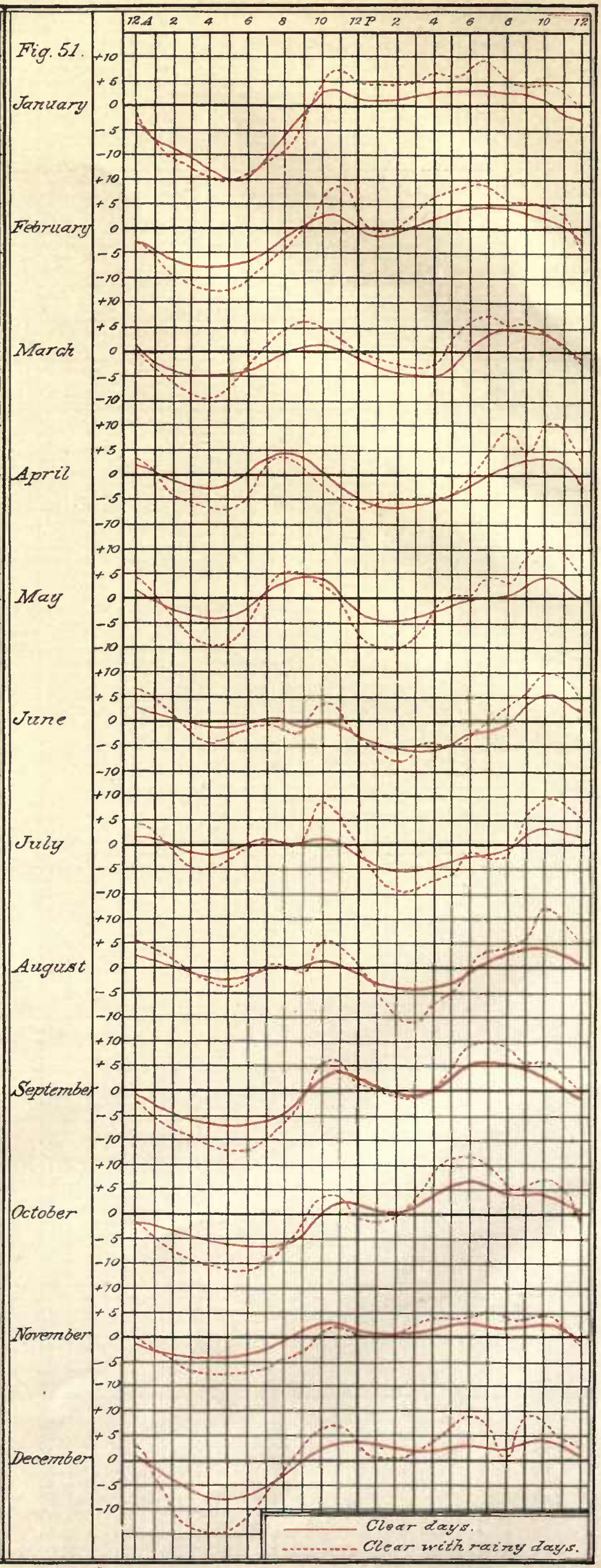


Fig. 51.
12A 2 4 6 8 10 12P 2 4 6 8 10 12
January
February
March
April
May
June
July
August
September
October
November
December
+10
+5
0
-5
-10
Clear days.
Clear with rainy days.

FIG. 52.—Coefficient of electric dissipation.

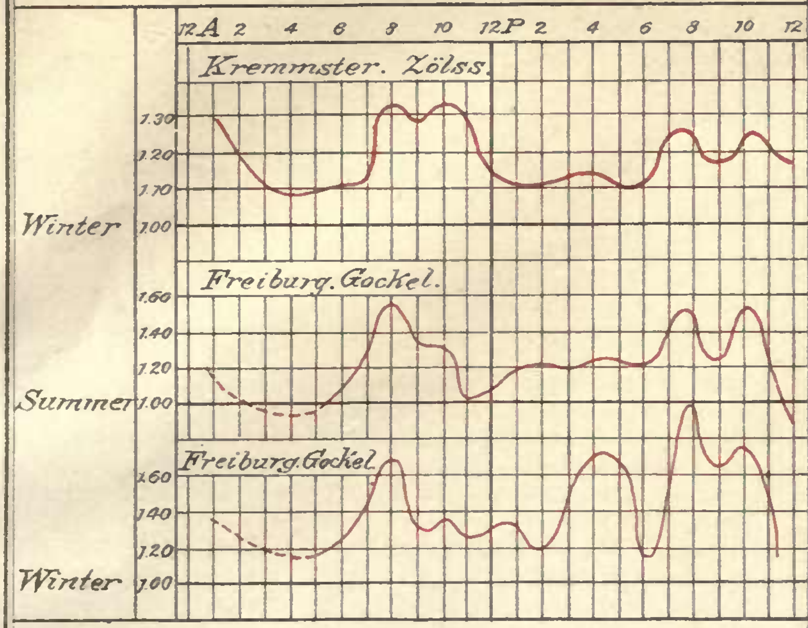
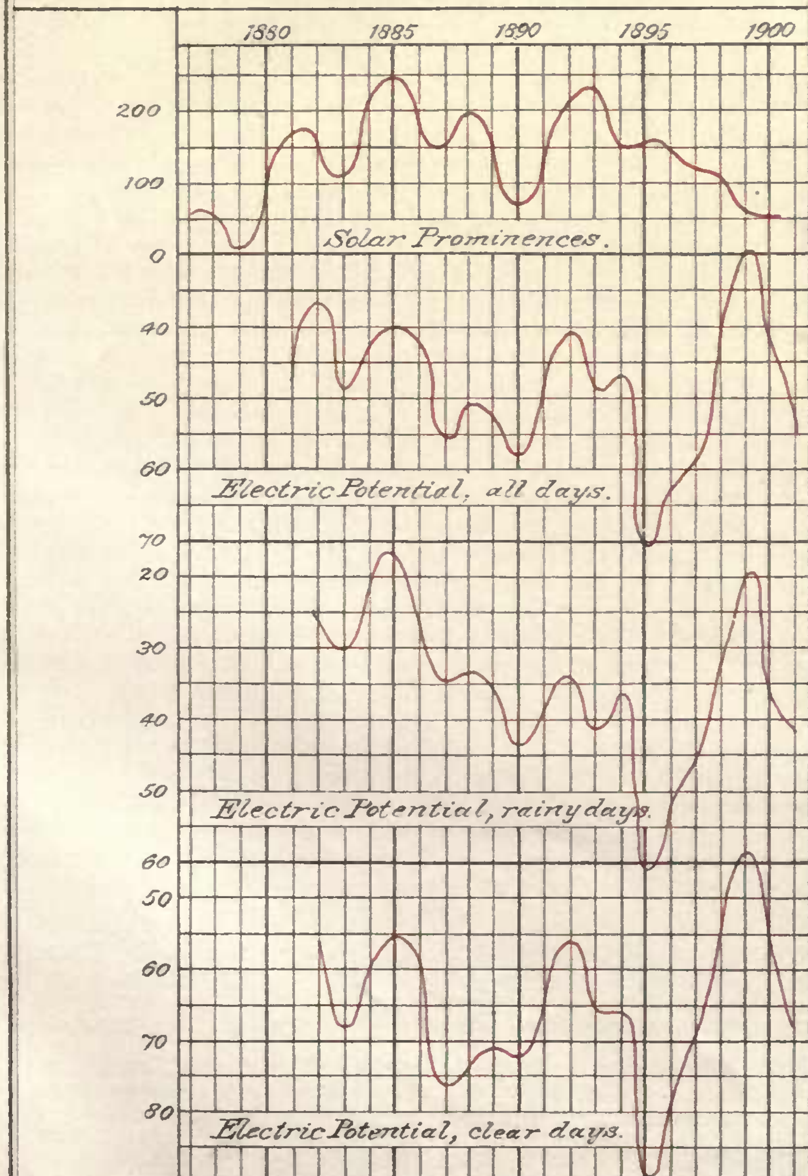
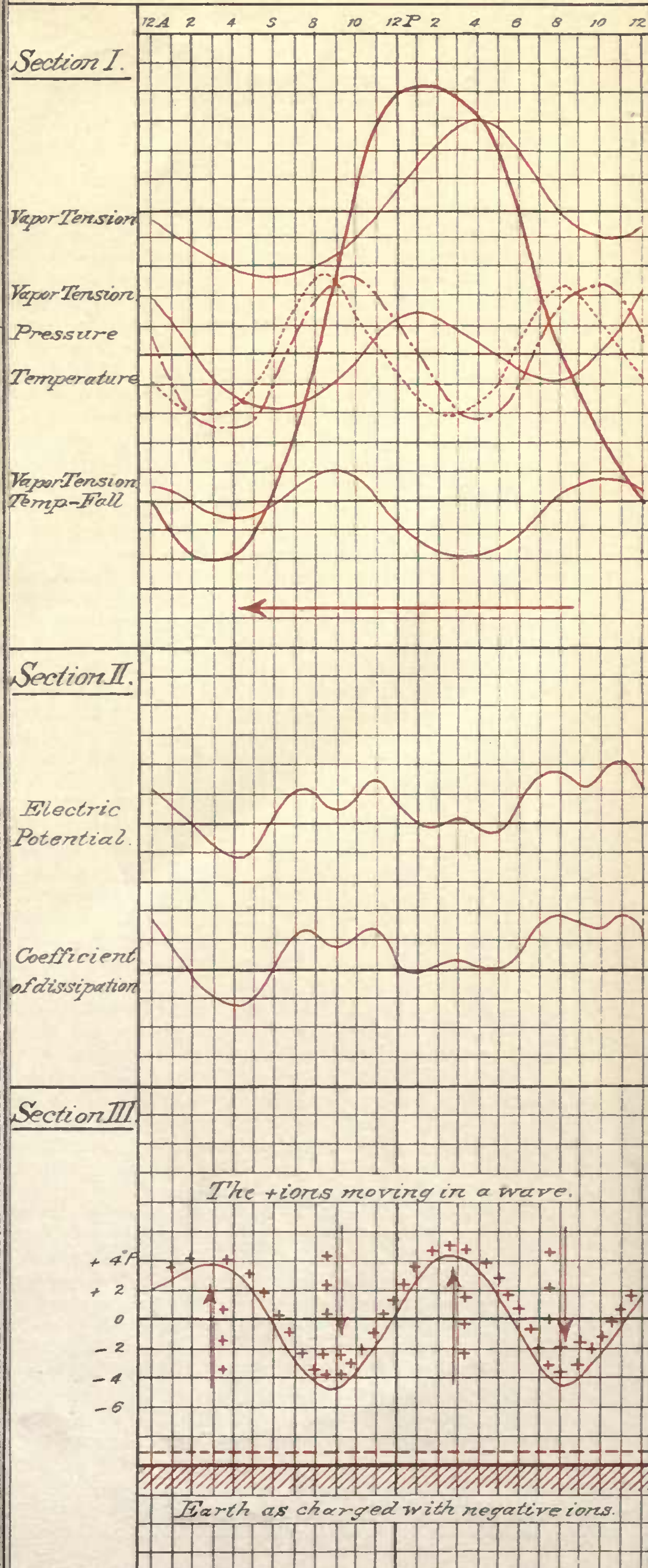


FIG. 53.—Annual variation of the number of the solar prominences and the atmospheric electric potential.



The atmospheric electric potential seems to be inverted relatively to the solar prominence frequency, and hence to solar activity; an increase of solar activity makes a decrease in atmospheric electricity gradient.

FIG. 54.—Comparison of the diurnal periods of the temperature-fall, pressure, temperature, vapor tension, electric potential, and coefficient of dissipation.



IV.—THE DIURNAL PERIODS OF THE TERRESTRIAL MAGNETIC FIELD AND THE APERIODIC DISTURBANCES.

THE DIURNAL VARIATIONS OF THE TERRESTRIAL MAGNETIC FIELD.

In the years 1889–1891 I computed a series of hourly magnetic deflecting vectors for 30 stations, in polar coordinates, $s =$ total vector, $\sigma =$ the horizontal component, $\alpha =$ the angular altitude positive above the horizon, $\beta =$ azimuthal angle counted from the north point of the magnetic meridian through the west $= 90°$, south $= 180°$, east $= 270°$. These were derived from the rectangular variations, ΔH horizontal force positive northward, ΔD declination positive westward, ΔV positive zenithward, by means of a simple scale diagram containing polar and rectangular coordinate systems at the same center. This presentation of the available data of observation included the diurnal variation of the magnetic field, and also the variation from day to day eliminating the hourly periodicity. The resulting tables are bulky and there has been no opportunity to publish them *in extenso*, but brief summaries of the subject matter have appeared in several places[1]. This work has aroused some critical discussion, but for the greater part of an academic character which threw little additional information upon the solution of the numerous difficult problems in solar physics and cosmical meteorology that are involved. It is quite evident that the authors of the comments did not always have in mind the details or the minor facts which must be accounted for in a final solution. It is easy to propose a vague general theory, but to bring it down to exact harmony with the many special peculiarities of the varying magnetic field is no easy problem to resolve.

In 1889 Schuster[2] published his solution for the diurnal variation of the *vertical* force derived from four stations, and ascribed to the assumed counterpart electric currents to a sensitive state of the *upper* atmosphere. In 1897 von Bezold[3] further discussed the subject as a continuation of the same data. In 1902 H. Fritsche[4] computed the variations from the difference data, ΔH, ΔD, ΔV, by means of Gaussian coefficients, and likewise attributed the magnetic effects to supposed electric currents in the upper atmosphere. In his paper of 1903, Adolph Schmidt[5] has adopted the method of deflecting vectors, and in his other papers seems to favor an electric current system in the high strata. Also, A. S. Steen[6] has worked out an elaborate system of upper air electric currents to account for the diurnal variation of the magnetic field.

Other writers, W. Sutherland, A. Nippoldt, W. van Bemmelen, J. Liznar, Carlheim-Gyllenskiöld, Ch. Chree, and L. A. Bauer seem to favor a solution of the same character.

I must confess that, aside from the entirely vague nature of this hypothesis, I have never been able to concede that it contains the true germ of the solution of the problem. That theory has received much additional popularity from the supposed bombardment of the upper strata of the earth's atmosphere by the ions ejected from the solar surface and transported to the region of the earth's orbit by the mechanical pressure of light, which were described as thereupon inducing the required electric currents. It was quite impossible to understand how such a general action of currents in the upper strata could produce the strongly localized effects observed at the surface of the earth, which so persistently follow the meteorological elements both diurnally and annually. I have, accordingly, (1) argued against the efficiency of these hypothetical upper strata electric currents to produce the details noted in the magnetic field, and I have (2) endeavored to show that the general motions of the atmosphere and the cyclonic and anticyclonic actions can not account for the observed phenomena, taken the world over, as shown by my 30-inch globe model of 1893.

It is true that my own working hypothesis was not complete even in my own mind, and I have supposed there are steps in the series of causes and effects that still require to be added. My view was simply this, that the sun's electromagnetic or radiant field of energy falling upon the atomic and molecular constituents of the earth's atmosphere transformed them into temporary magnetic states, by polarizing some of them *in situ*, that is, throughout the strata traversed by the solar energy. These temporary magnets produced a quasi magnetic field which deflected the normal field as observed. The deflecting forces were the products of the physical processes involved in this action of the radiation upon the atoms and molecules of the atmosphere. This theory was constructed before the phenomenon of ionization of the constituents of the terrestrial atmosphere by solar radiation had been discovered, and, of course, there was little scientific material to justify my hypothesis at that time. Furthermore, after the discovery of the existence of positive (+) ions and negative (—) ions as constituents of the atmosphere had been made, it still remained impossible to match the computed magnetic deflecting forces with the pressure and temperature period of diurnal variation as observed at the *surface* of the earth. The search for conclusive evidence of the synchronism of magnetic vectors and surface temperatures and pressures was always unsuccessful, but, fortunately, this defect now seems to have been overcome by the results of the computations summarized in this present series of papers upon diurnal pressure and temperature waves in the free air above the surface within one mile of the ground. The desired synchronism seems to be so perfect as to leave little ground for further doubt that the diurnal variation of the earth's magnetic field is due to the movement of the positive (+) ions of electricity in the lower strata of the atmosphere in streams that are induced and controlled chiefly by the diurnal temperature waves that prevail in the lowest strata. I shall, accordingly, consider this paper as a supplement to chapter 4 of Bulletin No. 21. The description of the magnetic vectors there given is correct and in agreement with the systems derived by later computers, but the process of producing them, as now understood, is in accordance with the facts that have been worked out since that paper was written.

[1] Weather Bureau Bulletin No. 2, 1892. Astrophysical Journal, October, 1893. American Journal of Science, December, 1894, August, 1895. Weather Bureau Bulletin No. 21, 1898. Weather Bureau Annual Report, 1898–99, chapter 9. Eclipse Meteorology and Allied Problems, 1902, chapter 4.

[2] The Diurnal Variation of Terrestrial Magnetism. A. Schuster, 1889.

[3] Zur Theorie des Erdmagnetismus. W. von Bezold, 1897.

[4] Die Tägliche periode der Erdmagnetischen Elemente. H. Fritsche, 1902.

[5] Eine Sammlung der wichtigsten Ergebnisse erdmagnetischer Beobachtungen. A. Schmidt, 1903.

[6] The Diurnal Variation of Terrestrial Magnetism. A. S. Steen, 1904.

THE DIURNAL MAGNETIC VECTORS AS THE EFFECT OF THE DIURNAL TEMPERATURE WAVES UPON THE REDISTRIBUTION OF THE POSITIVE IONS IN THE LOWER STRATA OF THE ATMOSPHERE.

This subject can be best presented to the reader by making a compilation of the vectors of the diurnal deflecting magnetic forces and as computed for the same latitudes as those represented by the meteorological stations that have been used in the comparison. For this purpose the following five stations have been selected, as they are located in the North Temperate Zone, but in widely distributed longitudes: Washington, Paris, Vienna, Tiflis, and Zi-ka-wei. Properly, Zi-ka-wei belongs partly to the Temperate Zone belt and partly to the Tropic Zone belt, magnetically considered, because it is so far from the north magnetic pole as to be immersed in the tropical influence during several months. Although this affects the azimuth of the hours during the night, I have not removed it from the group of stations. The computed values of s, α, β are extracted from the tables described in chapter 4, of Bulletin No. 21, and an example is given in full for the months of February and August in Table 10, "Hourly values of the polar coordinates, s, α, β, at five stations in the North Temperate Zone". The mean values were computed for each element at every hour, and these are given for each month in Table 2, "Vectors of the diurnal magnetic deflecting forces". s is in units of the fifth decimal or 0.00001 of the unit of the C. G. S. system; $\alpha =$ the altitude angle positive above the horizon; $\beta =$ the azimuth angle counted from the north through the west.

It is difficult to exhibit the results of the Tables 10 and 11 on a diagram of only two dimensions, and I have made use in my studies of globe models constructed of rubber balls with pins for vectors, or else the large 30-inch globe model already mentioned. However, a drawing has been made in fig. 55, "Diurnal variation of the magnetic vectors s, α, β for latitudes $+30°$ to $+60°$". The vector length s and the vertical angle α are plotted for each month, and the direction in azimuth β is laid down only for January and July, as the variation in this element is not very great in the course of the year. We should, therefore, interpret the vectors as follows: The vector (s, α) should be understood to stand in the plane of the azimuth β, and make with it the angle α which is here given. Generally, the vectors from 8 a. m. to 7 p. m. are directed toward the south, and those from 8 p. m. to 7 a. m. toward the north. As my purpose is to consider chiefly the relation of the streams of + ions in the air to the vector (s, α) I have practically sacrificed the azimuth in the diagram. On the globe model the entire system is clearly displayed and it should be studied in that way.

On fig. 55 there are seen to be four critical points in the distribution of the diurnal vectors:

(1) The first point marks a sudden increase in the value of the deflecting force s up to a maximum, and it occurs in the forenoon, ranging from about 8 a. m. in winter to 6 a. m. in the summer. This is the hour at which the azimuth β shifts from the northern to the southern quadrants. About two hours later the vertical angle α passes through 0° so that the vector changes from below to above the horizon.

(2) The second point occurs at 11–12 a. m. in winter and 10–11 a. m. in summer, where the azimuth β shifts from east to west through the south, this being the well-known reversal of the needle before noon. The value of s at this point is at a slight minimum relative to its values earlier and later; this midday minimum appears in nearly every month of the computation, but especially in summer.

(3) The third point occurs after the true midday maximum of s, about 3 p. m., where the vector (s, α) changes from above to below the horizon, and α passes again through the zero value of the angle. This point changes from about 2 p. m. in winter to 4 p. m. in summer, thus moving in the opposite direction from midday to that indicated in the forenoon vectors.

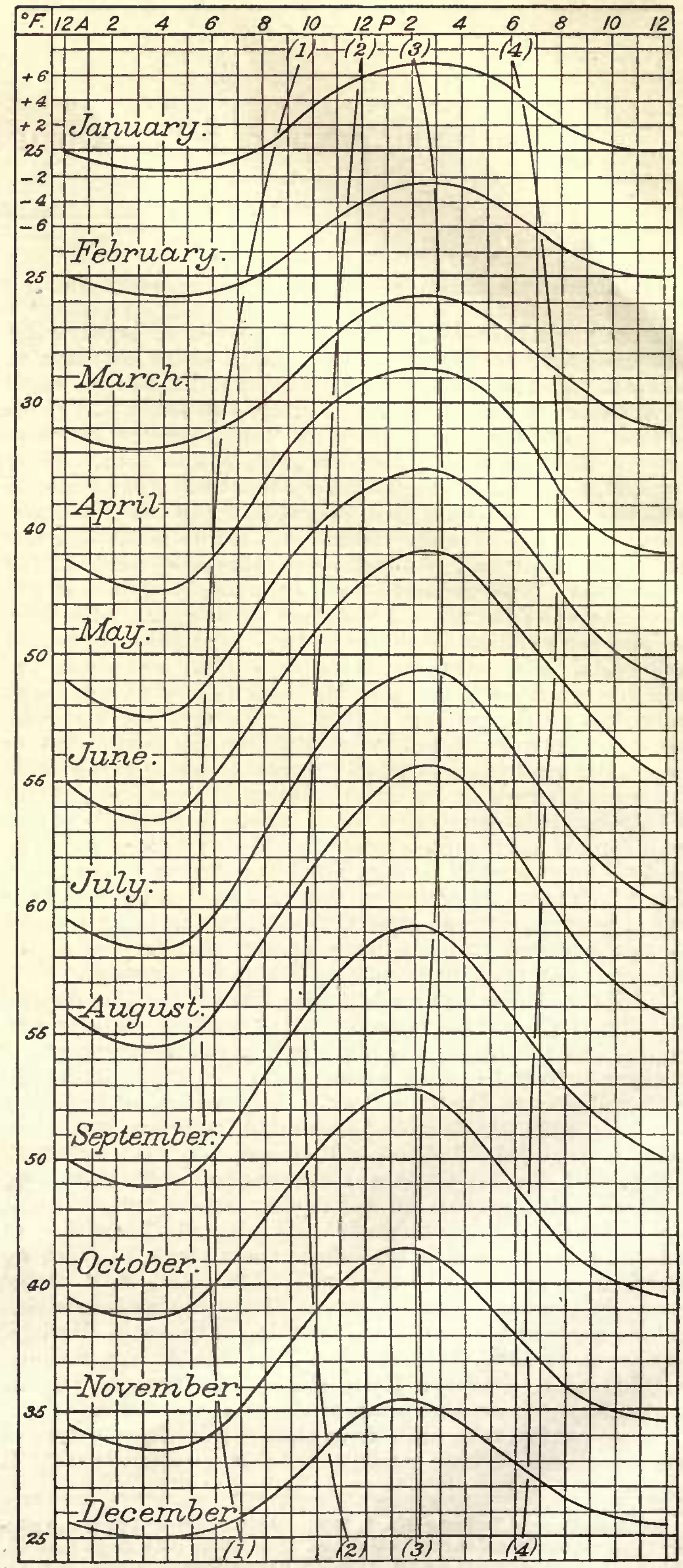


FIG. 56.—The annual variation of the surface temperature at Blue Hill.

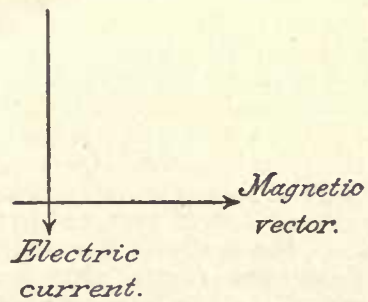
(4) The fourth point is where the azimuth β shifts from the first and second quadrants to the third and fourth, and it occurs at about 6–7 p. m. in winter, but at 7–8 p. m. in the summer, at the time of the setting of the sun. On fig. 55 these four special points in the system of diurnal vectors are indicated by the four lines marked (1), (2), (3), (4), and by

their course they show that the entire action which produces this magnetic disturbance of the normal field, contracts in time toward noon in the winter, and spreads away from it in the summer. This remarkable change in the location of the turning points is related without doubt to a similar change in the diurnal distribution of the temperature in the lower strata of the atmosphere, which must be closely associated with the magnetic variations.

In order to show how exactly these two phenomena synchronize in time during the course of the year, I have transferred to fig. 56 from figs. 14–25 the surface temperatures as observed at Blue Hill, plotting them in the sense indicated by the coordinate values. If the line (1) is drawn at the locus of the first active rise of temperature, at about two hours later than the minimum, the course is marked at an earlier hour in summer than in winter. The line (2) is drawn at about halfway up the forenoon temperature slope; line (3) at the maximum of the temperature, and line (4) at about halfway down the afternoon temperature slope. On comparing the lines (1), (2), (3), (4) of fig. 56 with those of fig. 55, it is observed that the annual curvature of the lines is generally so much in agreement as to make it very probable that the magnetic field and the temperature are both direct effects of the solar radiation, which itself has an entirely similar course to these in the North Temperate Zone. Now, since it is well known that this diurnal temperature effect is confined to the lower strata of the atmosphere, within two miles of the surface, I have been unable to concede that the diurnal magnetic variations can be caused by electric currents in the *upper* strata of the atmosphere, as assumed by Professor Schuster and other magneticians, or that it can be caused by a bombardment of the *upper* strata by the ions transported in the solar radiation, as supposed by Professor Arrhenius and other physicists. While I have been unable to relinquish my belief in a cause located in the *lower* strata of the atmosphere, it has been an exceedingly difficult thing to discover a substantial physical cause that will fix the exact location of a system of electric currents, or other source of these magnetic vectors, in this region, and, indeed, I had not been able to do so before arriving at the results of the kite observations as exhibited in the preceding papers of this series. We have been led, at length, very naturally to see in the movement of the positive (+) ions in streams, whose directions are determined by the temperature distributions in the lower strata, a sufficient cause for the diurnal variation of the electric potential field, and I shall now show that this cause also accounts equally well for the diurnal variation of the magnetic field in the North Temperate Zone.

The general relations may be represented schematically by fig. 57, "The probable relations between the temperature waves, the streams of positive (+) ions, and the magnetic vectors in the lower strata of the atmosphere". Let A represent the surface of the earth which is charged with negative electricity. A portion of this charge is derived from the ionized contents of the atmosphere, due to the action of the short waves of the solar radiation upon the constituents of the atmosphere, especially the aqueous vapor located within an arch spanning the Tropics. Another portion of the negative charge is probably derived from inside the earth, and is due to the excess of differential circulation of the negative (—) ions over the positive (+) ions in the atomic conflict at the prevailing high temperature and pressure, by which more of the negative electric ions are detached from the atoms and in circulating are polarized by the earth's rotation so as to produce the internal magnetism of the earth and an electrostatic charge at the surface. If the negative ions rotate more rapidly than the positive, as with the velocity of light, the deflecting force due to the earth's rotation must be large, and tend to cause these ions to move in planes perpendicular to the axis of rotation. This will cause an internal magnetic field directed from north to south.

The surface charge of negative ions is supposed to rest quite steadily on the earth, or within it, while the positive (+) ions of the atmosphere rise and fall from one stratum to another according to the change in the air temperatures, as if the positive (+) ions had an affinity for certain temperatures, which they seek through vertical and horizontal motions. Let B represent the ordinary surface temperature wave, with which it has never been possible to associate the diurnal magnetic vectors. Let C represent the semidiurnal temperature wave in the lower strata of the atmosphere as integrated in the diurnal convections, generally within half a mile of the ground. The maximum temperature occurs at 3 a. m. and 3 p. m., and the minimum at 8 a. m. and 8 p. m., both of these subject to the annual variation in time already indicated. Let D represent the probable streams of positive ions, directed vertically upward at 3 a. m. and 3 p. m., but downward at 8 a. m. and 8 p. m. It should be observed that at 3 a. m. the vertical upward current of the semidiurnal wave is really neutralized by the downward current of the surface wave, and that during the night hours we should have small residual motions on the whole of a downward direction; that, at 8 a. m. and 8 p. m. the downward semidiurnal waves prevail because the surface temperatures are nearly normal to the day and the convectional currents are producing lower temperatures; and, that, at 3 p. m. both the diurnal and the semidiurnal waves unite in a common upward vertical component. We may assume, then, that the positive ions descend vertically at 8 a. m. and 8 p. m., but ascend vertically at 3 p. m. The accompanying adjacent streams on the preceding side of the 8 a. m. vertical, bend to the left in the early morning hours, but to the right after that hour. These latter naturally recurve, becoming horizontal at 10 a. m. to 11 a. m. in order to ascend in the warm midday current. At 8 p. m. the positive (+) ions first descend, recurve by becoming horizontal at 6 p. m. to 7 p. m. and ascend in the warm afternoon current, while those farther to the right slowly descend throughout the night. Let E represent the corresponding magnetic deflecting forces, which are generally found to be at right-angles to the electric streams as thus located and always directed in the same sense.



This remarkably consistent correlation of cause and effect throughout the diurnal fields is greatly in favor of the theory here described. Finally, it should be remembered that this entire temperature system is moving as indicated by the arrow F on the diagram from right to left, and that the warm wave is continuously intruding upon the cool regions to the left of it. If the positive (+) ions seek to avoid an excess of warm temperature by streaming from low levels during the hours from 10–11 a. m. to 6–7 p. m. into the higher levels with a maximum at 3 p. m., that is generally by moving upward in the warm current, the effect is to leave the positive (+) ions in the higher strata throughout the evening and night hours. There is not so much a continuous electric circuit, with the same velocity in all parts of it as in a conductor, but rather an alternate rise and fall of the electric charges at different parts of the day, that is a falling by night and a rising by day, somewhat as is indicated in the diagrams. The westward lateral movement of the diurnal system probably tends to keep

wider open the streams of ions before noon, at 10 a. m. to 1 p. m., and to make them closer together at about 6 p. m. to 7 p. m. At the same time, as already explained, there is produced the increase of the atmospheric electric potential gradient to a maximum at 8 a. m. and 8 p. m. by the approach of the positive (+) ions to the negative (—) ions lying at the surface, also, an increase in the rate of dissipation of the two kinds of charges by the more immediate mixture and contact. It is not necessary to remark that we do not suppose that the positive (+) ions and the negative (—) ions are separated from each other so exclusively as is here indicated, but only that there is an excess of the positive (+) ions in the strata above the ground, and an excess of the negative (—) ions near the surface. It may be noted that the conflict in direction from 4 p. m. to 9 p. m. between the convection air currents and between the streams of the ions, one being upward and the other downward, is very favorable to the production of thunderstorms.

THE DIURNAL MAGNETIC VECTORS IN THE POLAR, TEMPERATE, AND TROPICAL ZONES OF THE EARTH.

Similar considerations applied to the magnetic hourly vectors which have been computed in the other zones of the earth, and described in chapter 4 of Bulletin No. 21, lead to the following conclusions, illustrated schematically in fig. 58. The normal magnetic field of the earth, positive in the Southern Hemisphere, has the horizontal component directed northward, while the vertical is upward in the Southern Hemisphere, but downward in the Northern Hemisphere. The downward positive (+) ion stream repels the north end of the magnet eastward in the North Temperate Zone, but westward in the South Temperate Zone; the upward positive (+) ion stream works in the opposite sense. Hence, the descending positive (+) ion stream from 7 p. m. to 11 a. m. (fig. 57) in the Northern Hemisphere directs the north end of the needle eastward, but in the Southern Hemisphere, westward. The ascending stream directs it westward in the Northern Hemisphere and eastward in the Southern Hemisphere. The same diurnal temperature waves, therefore, produce the required opposite magnetic effect in the respective hemispheres. In the Tropical Zone the vectors on the sunward side are directed northward for the ascending positive (+) ion streams, and southward in the night, 4 p. m. to 8 a. m. for the descending streams. In the Polar Zone the outspreading magnetic sheets on the morning side of the pole imply a descending stream of ions which is directed from left to right, or west to east; and on the afternoon side the ascending and concentrating magnetic vector sheets imply an outflowing system of positive (+) ions which ascend into regions about the surface. Generally, these magnetic vectors in the three zones require electric currents directed from west to east in the Polar Zone athwart the direction of the lines of the solar radiation; those in the Temperate Zones require lines nearly in planes from north to south, and also athwart the solar radiation field; finally those in the Tropics require positive (+) ion streams parallel to the direction of the same radiation. These three rectangular systems of electric currents evidently form those types of couples, exactly the counterparts of the three sets of magnetic couples which were described in the same chapter of Bulletin No. 21. For some reason the positive (+) ions seem to prefer to travel at right angles or else parallel to the lines of the electromagnetic radiation, even when they are passing along paths which are rendered favorable by the temperature conditions already existing in the lower strata of the atmosphere. It is evident that these prevailing conditions imply a possible solution of several important physical questions in electricity and magnetism in the earth's atmosphere, when suitable observations have been acquired. The theory which I advanced to account for the observed diurnal magnetic vectors in my preliminary papers is now much more satisfactorily stated, by such an addition to its terms as has been drawn from the process depending upon the ionization and temperature effects of the solar radiation in the lower atmosphere. Apart from clearness of exposition, it seems to me that the view there advanced, namely, that the magnetic vectors are products of the electromagnetic radiation as the result of its action on the atoms of the atmosphere is substantially strengthened. The entire subject, though intellectually more satisfactory, is also much more difficult to handle scientifically, because the intermediate steps involved in the action of the ions in relation to the temperature, must be worked out by observations in the lower strata of the atmosphere, and such data are very difficult to acquire in a reliable form.

THE SYSTEM OF DAILY MAGNETIC VECTORS, AS DISTINCT FROM THE HOURLY VECTORS.

Besides the system of hourly deflecting magnetic forces described in chapter 4, Bulletin No. 21, I also worked out a second vector system, which gives the vectors day by day, disturbing the normal magnetic field in the day intervals, taking the several successive groups of 24 hours in succession. These vectors are summarized in chapter 3, of the same bulletin, and it was there shown that they consist of vectors acting nearly in the planes of the magnetic meridians directed northward or southward as the case may be. Since the entire magnetic field of the earth is involved in these disturbances, which often run three or four days in the same direction, before reversal to the other side of the normal occurs, it is necessary to seek for a general cause instead of one that is distinctly local. The mere temperature effects of meteorological circulation can not be the dominant cause, because the two systems of conditions do not synchronize. It was also shown that this general magnetic field, taking the annual values of the vector *s*, does vary in parallel with that of the solar field as shown by the frequent number of spots, faculæ, and prominences. According to that interpretation of several phenomena which was adopted and which is probably physically correct, the sun was found to be magnetized. The solar action and the magnetic terrestrial effect undoubtedly synchronize in the long run, but there has been great difficulty in assigning so large physical fluctuations to the sun itself as seem to be required to account for the observed magnetic conditions at the earth. It has seemed to me necessary to assign to the direct magnetic field of the sun at least the function of setting in operation such terrestrial forces in the earth's atmosphere as should make up between them the required magnetic efficiency. Just what that terrestrial process is in fact, there has been trouble in detecting, and in assigning to it a sufficiently natural *modus operandi*. The violent fluctuations of the magnetic field could hardly be ascribed exclusively to variations in the normal solar electromagnetic radiations, for two reasons: (1) The sun would be a variable star of such a convulsive type as to be inconsistent with the comparatively steady flow of heat which the earth receives from it. Nor can this view be suitably modified by adding such a bombardment of solar ions as Arrhenius has suggested, because their possible efficiency is not nearly great enough to match the great magnetic fluctuations which are continually being recorded. (2) The vector system pertaining to these daily disturbances is entirely different in type from that found in the hourly variations. Indeed, I showed by the computation on Table 15, page 76, Bulletin No. 21, that in the case of strong disturbances the ordinary hourly disturbing vectors (fig. 58) are transformed hour by hour into a system of vectors like the general type (fig. 59), thus proving that these two phenomena have essentially different originating causes, so far as their effects on the observed magnetic vectors are concerned. I have not failed to recognize the difficulties of my own theories in this problem, nor have I discovered in other papers a solution which seemed in anywise competent

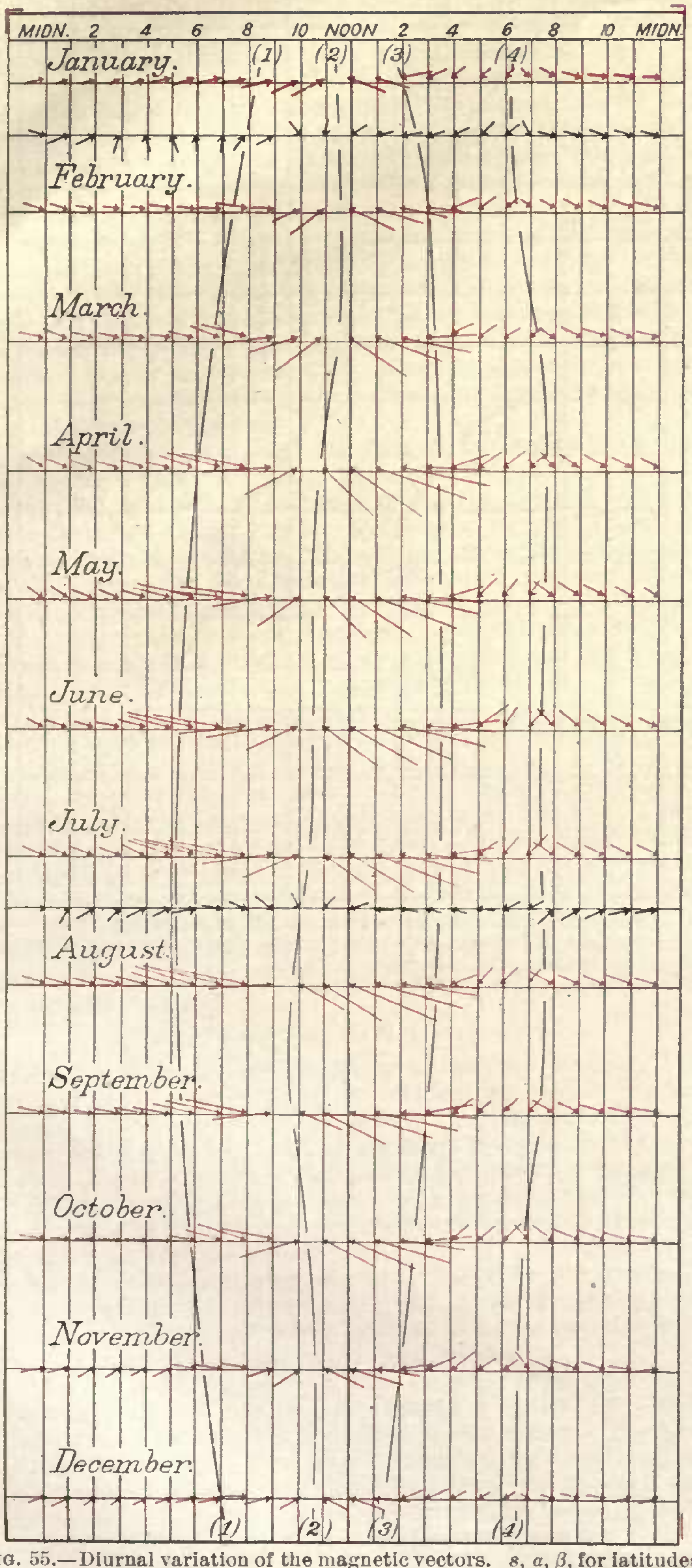


FIG. 55.—Diurnal variation of the magnetic vectors. s, a, β, for latitudes $+30°$ to $+60°$; s, a, for each month, β, for January and July.

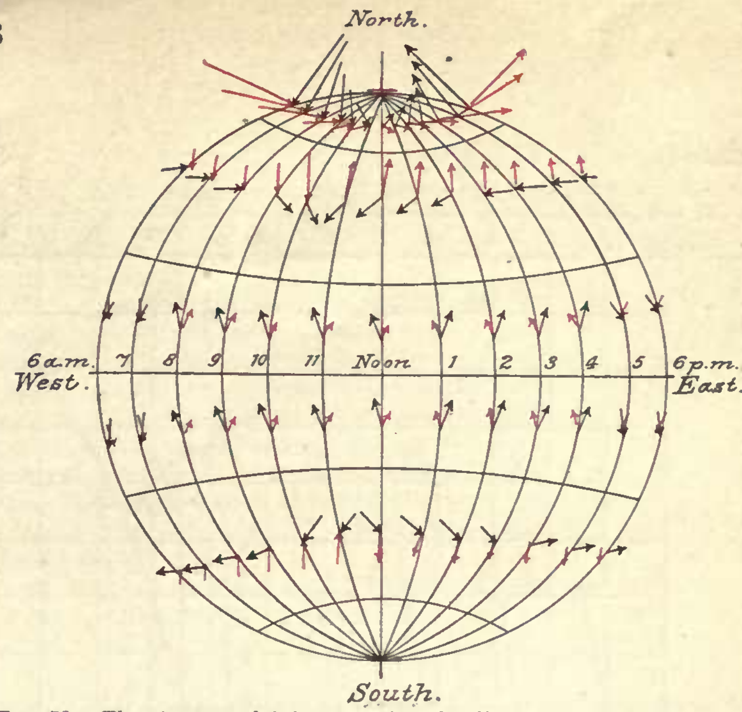


FIG. 58.—The streams of + ions causing the diurnal magnetic vectors in the Polar, Temperate, and Tropical zones of the earth.

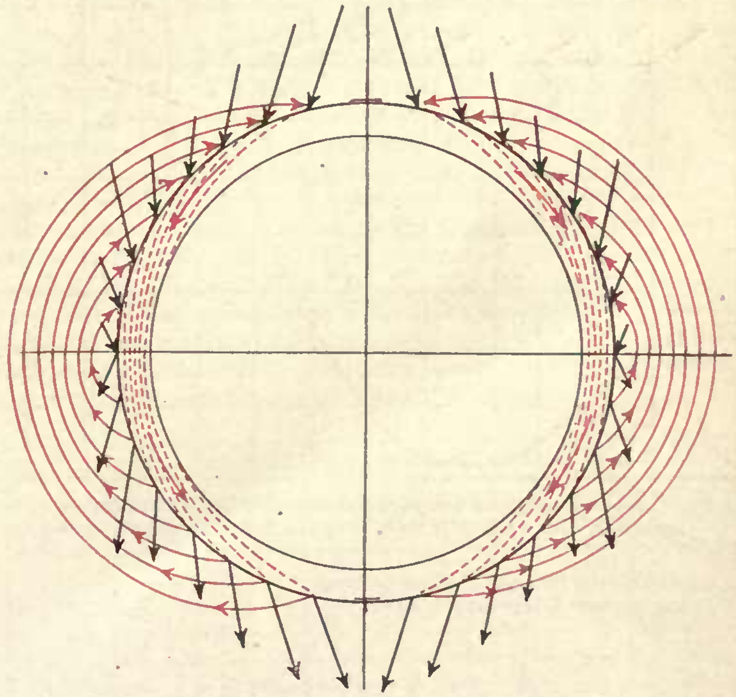
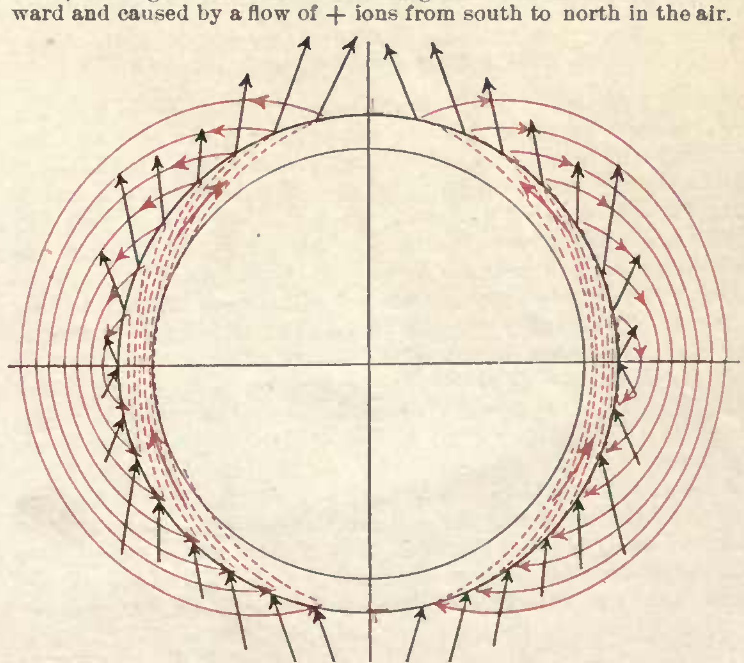


FIG. 59,—The general disturbance: Magnetic vectors directed southward and caused by a flow of + ions from south to north in the air.



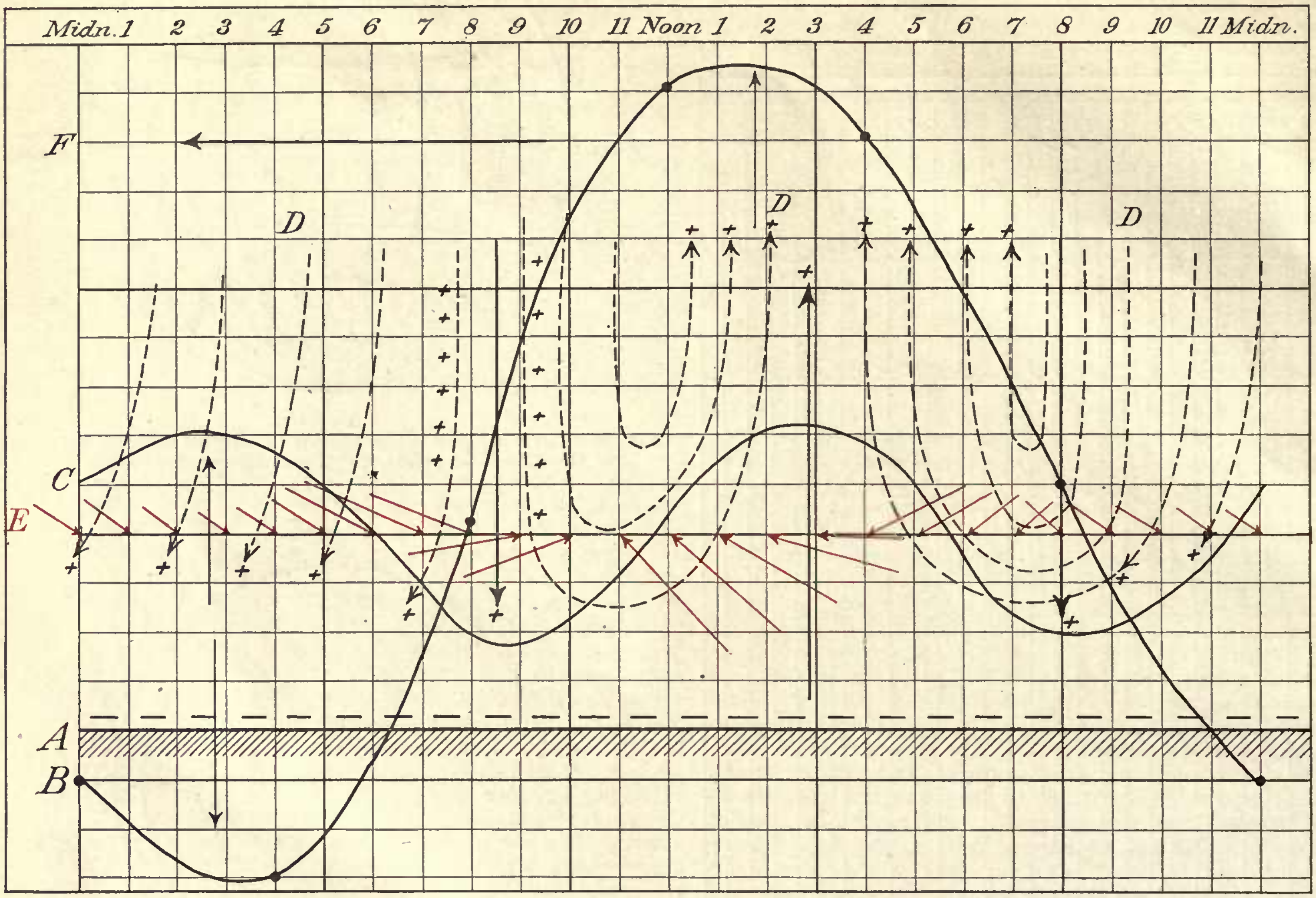


Fig. 57.—Probable relations between the temperature waves, the streams of + ions, and the magnetic vectors in the lower strata of the atmosphere.

A = negatively charged surface of earth.
B = the surface temperature wave.
C = the semidiurnal temperature wave at the height of 400-600 meters.
D = the probable stream lines of the positive ions, as moving charges.
E = the corresponding magnetic vectors.
F = direction of motion of the system.

to account for all the conditions at the solar end and at the terrestrial end of the line of cause and effect. The following view is, therefore, suggested with the impression that it forms an excellent working hypothesis for further examination.

Taking such a group of lines of force as are to be found on charts 17, 18, of Bulletin No. 21, which shows that the magnetic force is subject to world-wide variations of the same type on the same dates, it is evident that the normal field of the entire earth is for a while disturbed by a set of vectors pointing southward, and again by a set of vectors pointing northward. The mean vectors of this system at the several latitudes of the earth were computed, and they are plotted on chart 10 of Bulletin No. 21. They have longer vectors in the polar regions and in latitudes 20° to 40° than in the latitudes 40° to 60° and 0° to 20°. I have transferred them to fig. 59, which shows the magnetic vectors s directed southward and to fig. 60, which shows them pointing northward, of course referring to two seperate occasions. This alternate action, or reversal of the entire system of magnetic deflecting forces, is the phenomenon to be explained.

By extending our notion of streams of positive (+) ions moving from point to point in the atmosphere, we have merely to suppose that on certain provocations the positive (+) ions move from one hemisphere to the other in the atmosphere, returning again through the outer shell of the earth, as indicated on the diagrams. For a southward directed magnetic system, the positive (+) ions stream from the Southern Hemisphere along the arches in the atmosphere most favorable to their movement, whether due to temperature and vapor conditions, or to special ionization and conductivity functions. This flow of the positive (+) ions induces the magnetic vectors at the surface, and the positive (+) ions stream back from the Northern Hemisphere to the Southern through the crust of the earth, thus causing the earth currents which always accompany agitation of the normal magnetic field. For a northward directed system of vectors the positive (+) ions stream from the Northern to the Southern Hemisphere in the air, and return thence through the outer shell of the earth. The magnitude of the disturbance of the normal magnetic field depends upon the intensity of the stream of ions flowing along these paths, and that is a function of the number of the ions and the velocity of their motion,

$$\lambda = e\,(n_+ v_+ + n_- v_-),$$

where e is the charge of electricity of each ion, n_+ and n_-, the number of the positive (+) ions and the negative (−) ions, and v_+ and v_-, the velocity of the same. The simultaneous occurrence of the aurora in both hemispheres is evidence of the action of the ions which, in traversing the gases of the atmosphere in the low or the high strata, produce the observed luminous effects as phosphorescence or fluorescence. It should be observed that the hourly location of the aurora frequency occurs in the regions marked out on fig. 58 by the streams of ions, that is in the early morning and the early evening hours, since there is a region of minimum of frequency stretching from 11 a. m. across the polar region to 11 p. m.

This simple explanation of the long series of interrelated phenomena, which has so long escaped a natural correlation, has much to commend it to careful consideration. The quantitative determination of the number of ions involved, and their velocity of motion in the circuit from one hemisphere to the other, will require much exact research work upon the various functions involved in the physical processes.

THE DISTRIBUTION OF THE APERIODIC DISTURBANCES.

It has been very difficult to assign to the observed disturbances of the magnetic field, that is to the large variations of a spasmodic character, like temporary storms, which occur in the normal field, a satisfactory explanation. The attempt to ascribe the physical cause exclusively to variations of the solar action *in situ*, that is in the sun itself. as for example, the sun spots, or the prominences, is attended with unusual troubles of a physical nature. The following analysis may tend to throw some light on the subject.

The disturbances which occurred at Washington, D. C., during the years 1889, 1890, and 1891 were subjected to an analysis similar to that used in other connections, by which the polar disturbance vectors σ, s, a, β, were computed for each half hour of those days on which the traces were decidedly agitated, as 1889, February 28, 29, March 5, 6, 17, and so on throughout the three years. The purpose was to fix their daily distribution as a diurnal period, and the direction from which they come upon the normal field. The mean vector for the 24 hours was,

$s = 245$ for β	between	315°	and	45°	that is	north;
315 " β	"	45°	"	315°	"	west;
333 " β	"	135°	"	225°	"	south.
308 " β	"	225°	"	315°	"	east.

Hence, the south quadrant receives the strongest impulse, while the east and west quadrants are more disturbed than the north quadrant. Fig. 61 contains the curve of relative numbers showing the diurnal frequency of the disturbance, the maxima being at 12 to 1 p. m. and 12 to 1 a. m. Comparing with fig. 57, it is seen that these maxima agree with the position of the maxima of intensity of the ascending stream of positive (+) ions, as determined by the temperature curve of the lower strata, that is the one located a few hundred meters above the surface. We may infer that one source of the magnetic disturbances is in the temperature waves which induce the movement of the streams of positive (+) ions, especially in a vertical direction. Hence, these hourly magnetic disturbances are specifically meteorological phenomena occurring in the lower strata of the atmosphere, and are the products of the solar radiation produced through the intermediate agency of the ionization and temperature waves.

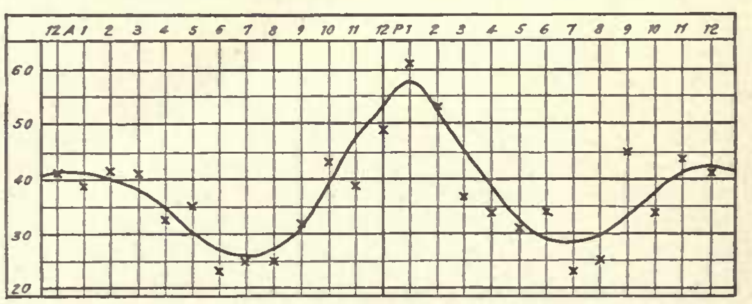


FIG. 61.—Distribution of the hourly magnetic disturbances at Washington, D. C., in the years 1889, 1890, 1891.

There is yet another cause for the other type of great magnetic storms which endure for several days, as distinct from those lasting a few hours, and cause the excessive variations in the diurnal field. In working up my data into the 26.68-day period, and deducing the resulting mean magnetic curve, as shown on chart 21, Bulletin No. 21, or by the upper curve on fig. 62, I excluded the large magnetic disturbances beyond a certain amplitude, for the sake of obtaining the normal structural magnetic impulse due to the rotation of the sun on its axis, if any such exists. The curve mentioned has been found to reappear generally, though at the expense of much waste of material in computing to eliminate the other kinds of irregularities by mutual self destruction, in nearly all the solar and terrestrial phenomena. It, therefore, seems to point to an organized mass in the sun due to a highly viscous mass having great rigidity at immense pressure, or to a definite organic circulation. Similarly I have counted out the dates of occurrences of the magnetic disturbances recorded at Greenwich, 1882–1903, as collected by Mr. Maunder in his paper,

Monthly Notices R. A. S., November, 1904, and entered them in a table based upon the 26.68-day ephemeris. The result is shown also in fig. 62, and it seems to imply that the 26.68-day period is at the basis of the distribution of the great magnetic storms, rather than the 27.35-day period, which is the average in the sun-spot belt.

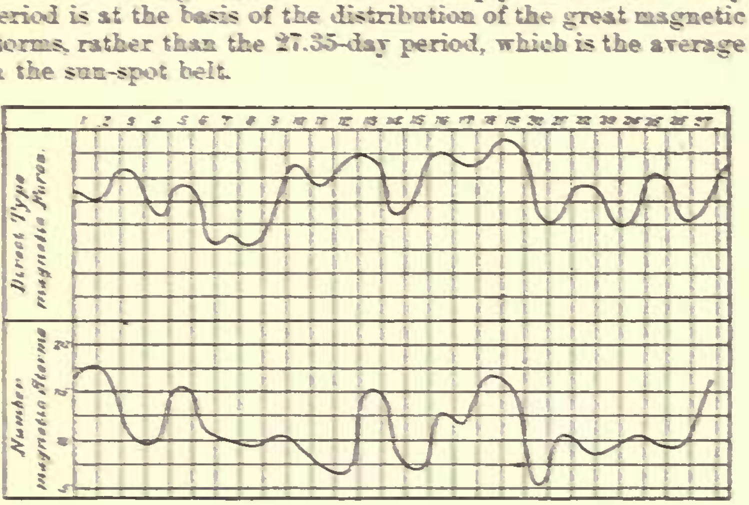


FIG. 62.—Distribution of the great magnetic disturbances in the 26.68-day period (Maunder's data).

In Terrestrial Magnetism, Vol. X, p. 12, March, 1905, Ch. Chree gives a table which shows the number of great magnetic storms, using Maunder's data, that commenced on the several hours of the day. These numbers are plotted on fig. 63 which shows that there is a distinct maximum at 1 p. m. The numbers are distributed without distinction as to hours during the night and early morning, but at 10 a. m. a pronounced increase in the number per hour set in which culminates at 1 p. m. and falls off gradually to 8 p. m. On comparing this curve, fig. 63, with that of the diurnal disturbance curve, fig. 61, it is seen that the principal maxima agree at the same hour. The inference is that the great disturbances lasting several days, as well as disturbances which are limited to a few hours in duration, each tend to concentrate about the 1 p. m. hour when the ascensional current of the positive (+) ions is strongest. From figs. 62 and 63 it is quite certain that the great disturbances have two terms entering into their composition, one belonging to the sun's atmosphere and the other to the earth's atmosphere. The final solution of this problem is evidently dependent upon a knowledge of many terms other than a mere enumeration and matching of the number of the sun spots and prominences with the magnetic traces.

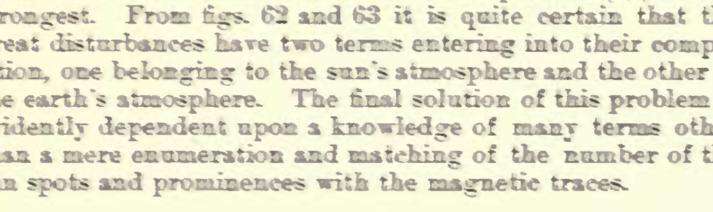


FIG. 63.—Number of great magnetic disturbances commencing at the several hours (C. Chree's Table, Terr. Mag. Vol. X, No. 1, p. 12).

The physical impulses from the sun to the earth may come in two ways, (1) by the radial path of the solar radiation, and (2) by the curved path of a direct magnetic polar field. Either of these may operate separately, or both of them may work together, to alter the normal balance among the positive (+) ions in the earth's atmosphere, and thus start them flowing in the paths indicated on figs. 58, 59, southward or northward as the case may be. As a matter of fact, the great magnetic storms lasting two or three days are found to require a deflecting vector system pointing southward, so that the positive (+) ions flow northward in the air strata. They may continue to flow as long as the solar impulse, whether of radiation or of direct magnetic field, is passing the position of the earth in its orbit. On this view the strain is removed from the original theory that the sun can not by direct action as a magnetic sphere influence the earth to the full extent required by the observations, because only a part of the energy traverses the cosmical space from the sun to the earth, while the remainder is simply due to the streams of ions in the atmosphere flowing as adjustment currents.

Enough has been shown, I believe, to make it clear, (1) that the variations of the terrestrial magnetic field are distinctly meteorological effects, and should properly be examined by the meteorologist rather than by the geophysicist; (2) that this interaction of the electric, magnetic, and temperature effects, whether at the sun or at the earth, constitutes one of the most fascinating problems open to scientific research. If the production of ions by solar action, their distribution statically and dynamically under the influence of atmospheric pressure, temperature, and vapor contents can be thoroughly worked out, the result will be to raise meteorology to a practical science of the highest rank. The numerous cross connections between radiation, whether variable or constant, the ionization in the solar and in the terrestrial envelopes, the consequent circulation of the solar mass and of the earth's atmosphere, the resulting weather and climates, make up a series of research problems of much difficulty, and yet of such promising value to all men as to justify a much greater activity on the part of astrophysicists and meteorologists than has been given to the subject of cosmical meteorology in the past.

THE COMPONENTS OF THE DIURNAL WIND VELOCITY.

In chapter 9, of the International Cloud Report, some account was given of the relation between the distribution of the pressure waves and the magnetic field vectors in the polar regions, as well as in the Tropics and middle latitudes. It was shown that the diurnal wave in the Tropics and the temperate zones advances over the earth as a long double wave extending from latitudes +60° to −60°, but that in the Polar Zone a single wave of maximum crosses the poles with a phase about 90° different from either of the maximum pressure waves in lower latitudes. It appears that the distribution of the magnetic vectors is closely associated with this single pressure wave in the Arctic regions, but I could give no suitable explanation of this sudden transition from the double to the single wave at the latitude 60°. It now appears that the semidiurnal waves are due to temperature effects and convection currents in the lower strata, as within 600 meters of the surface, and that above them from 600 meters to 3000 meters there exists a single temperature wave, located halfway between them, which likewise is produced as the result of the temperature distribution in the lower strata. Now, since in the temperate zones, the double temperature waves exist at low levels and the single temperature wave at high levels, it is quite likely that this single wave descends to the surface in the Polar Zone, and induces the single pressure wave which accompanies it. Thus, the single temperature and pressure waves rest on the surface in the polar zones, but pass overhead as an arch in the temperate and the tropical zones, higher in the Tropics than in the middle latitudes. This is quite similar to the distribution of the aqueous vapor contents in an arch, and it is probable that the positive (+) ions travel along this high pressure arch through the earth's atmosphere rather than by any other route. The vectors of figs. 59, 60 show that long vectors occur in the Polar Zone, and in the latitudes between the eastward drift of the temperate zones and the westward drift of the Tropics, that is to say, in the belts of the earth where the high pressure distributions come to the surface. The cloud belts of the Temperate Zone, latitudes 40° to 50°, and near the equator, +10° to −10°, apparently impede the circulation of the streams of ions and so produce short disturbing vectors in those belts.

Finally, by comparing the diurnal wind vectors, as deduced from the surface and the free air observations, it will be seen that they harmonize closely with the other results of this analysis. I may remark in conclusion, that there seems to be little need to adopt the theory of Arrhenius, that the magnetic disturbances are due to a bombardment of the solar ions traversing the space between the earth and the sun, because the disturbance of the normal temperature, or the normal electrical field and magnetic field by radiation effects, or by the direct magnetic effects, is sufficient to set up a counterbalancing circulation of the ions. The entire system of the sun and the earth constitute a delicately balanced wireless telegraphic system, and the ions may be regarded as sensitive coherers, which respond to every impulse tending to disturb the equilibrium. It should be especially observed that the variation of the magnetic field at the surface most effectively and simply integrates the entire efficient energy expended in these several types of force. If the temperature waves in the lower strata disturb the ions, and these induce the magnetic deflecting forces, then, in the inverse order, the magnetic force at the ground measures the nature of the temperature wave passing overhead. In this aspect of the case the magnet can be made to register the temperatures in the lower strata of the air at least indirectly, and probably very efficiently, when the function becomes fully understood, and in this sense a magnetic observatory is essential to the progress of the higher meteorology.

TABLE 10.—*Hourly values of the polar coordinates s, α, β at five stations in the North Temperate Zone.*

W. = Washington. P. = Paris. V. = Vienna. T. = Tiflis. Z. = Zi-ka-wei.

FEBRUARY.

Hours.	s W	s P	s V	s T	s Z	Means.	α W	α P	α V	α T	α Z	Means.	β W	β P	β V	β T	β Z	Means.
12 a	4	10	9	9	7	8	−28	− 5	−12	−12	− 8	−13	273	276	302	297	180	265
1	8	5	6	10	6	6	−25	−10	− 7	−11	−18	−14	234	261	320	261	160	259
2	2	3	13	7	7	6	−26	0	+ 4	−16	− 7	− 9	349	288	337	286	195	271
3	1	4	6	3	7	5	−27	0	0	0	− 6	− 7	280	280	336	315	195	279
4	2	3	9	3	5	4	−20	0	− 6	0	0	− 5	292	288	340	378	180	296
5	4	3	16	5	6	7	−46	+17	− 7	+11	−16	− 9	309	315	352	360	190	305
6	4	5	15	6	7	7	−23	+11	− 4	+ 9	− 6	− 3	309	323	348	398	180	312
7	7	7	16	6	8	9	−21	+ 9	− 6	0	+ 9	− 2	318	393	347	258	162	282
8	10	7	22	13	9	12	−10	+ 8	−10	0	− 6	− 4	301	226	229	322	206	287
9	11	6	20	14	9	12	− 4	+ 9	− 4	+12	0	− 3	289	279	290	294	308	292
10	10	7	20	10	13	12	+ 6	+27	+10	+37	+16	+20	271	211	236	268	305	257
11	8	11	34	10	12	15	+23	+34	+25	+61	+26	+34	228	144	200	142	333	209
12 p	12	16	40	16	15	20	+22	+23	+22	+40	+23	+26	153	106	160	160	6	105
1	16	19	31	18	19	21	+18	+15	+16	+27	+19	+18	126	93	145	90	27	97
2	16	15	31	16	16	19	+13	+12	+13	+11	+ 7	+11	100	94	124	94	33	89
3	16	10	24	14	12	15	+ 9	0	− 3	− 4	+ 5	+ 1	87	96	111	116	34	89
4	10	7	15	11	7	10	+12	−16	−16	−15	−45	−16	81	117	102	128	36	98
5	6	4	10	10	5	7	+23	−35	−29	−23	−90	−31	86	90	122	129	0	85
6	6	4	6	9	6	6	+18	−57	−45	−36	−45	−33	91	90	75	164	180	120
7	3	3	4	7	5	4	+23	−45	−65	−45	−22	−31	245	295	65	217	180	200
8	2	5	6	6	10	6	−23	−21	−45	−45	0	−27	279	215	333	210	191	265
9	4	6	10	8	9	7	−26	−18	−29	−30	− 6	−22	256	288	306	254	167	257
10	6	7	12	8	7	8	−25	− 8	−20	−40	− 8	−20	271	286	304	260	172	268
11	6	8	18	6	8	8	−31	− 7	−18	−30	−18	−20	286	278	308	270	168	260
12	4	10	9	9	7	8	−28	− 5	−12	−12	− 8	−13	272	276	302	297	180	265

AUGUST.

Hours.	s W	s P	s V	s T	s Z	Means.	α W	α P	α V	α T	α Z	Means.	β W	β P	β V	β T	β Z	Means.
12 a	5	10	13	9	3	8	−10	−17	−13	−21	−18	−16	360	315	228	320	135	292
1	7	9	10	10	2	8	+ 5	−13	−17	−17	−26	−14	445	319	315	307	360	329
2	6	6	9	9	7	8	+ 6	−15	−18	−13	−26	−13	341	320	297	306	342	321
3	5	9	13	10	11	10	+12	− 6	−12	−17	−38	−11	352	305	300	294	225	316
4	6	10	13	11	14	11	+19	−11	−18	−22	−30	−12	292	286	297	294	331	300
5	10	12	16	16	20	15	− 2	−14	−20	−22	−33	−18	303	279	298	267	320	297
6	21	16	18	23	40	24	− 6	−15	−22	−18	−25	−18	285	266	280	270	297	280
7	31	21	20	32	49	31	− 1	−11	−20	−16	−16	−13	272	252	279	254	278	267
8	36	23	22	35	46	32	− 1	− 4	−21	− 9	−10	− 9	151	232	236	240	271	226
9	34	22	28	31	25	27	+ 6	+14	− 9	+ 5	−21	− 1	225	218	209	217	265	227
10	25	20	28	21	12	21	+16	+30	+15	+28	+56	+29	163	174	177	186	90	162
11	22	26	35	22	31	27	+22	+35	+31	+40	+26	+31	155	133	157	114	80	128
12 p	32	35	40	35	43	37	+13	+30	+32	+27	+15	+23	112	96	118	67	78	98
1	32	34	37	40	43	37	+11	+20	+25	+17	+ 8	+16	98	97	101	77	72	86
2	29	30	30	37	32	32	+ 4	+10	+15	+14	+ 4	+ 9	61	97	84	71	67	80
3	21	20	21	27	27	21	− 5	− 6	+13	+ 6	− 3	+ 2	71	86	61	72	65	75
4	13	13	12	15	3	11	−29	−33	−14	0	−18	−19	51	80	85	74	90	76
5	9	9	4	6	16	9	−43	−72	−63	−39	−15	−46	38	45	90	90	165	86
6	7	10	4	4	23	10	−46	−72	−45	−75	−16	−51	14	315	315	180	190	63
7	5	10	9	4	22	10	−40	−45	−20	−58	−15	−36	350	343	346	90	177	45
8	6	11	12	5	15	10	−21	−33	−20	−63	+ 3	−27	348	334	350	360	176	314
9	5	10	14	6	0	9	−26	−29	−17	−45	0	−23	345	319	346	329	262	320
10	6	11	12	6	11	9	−31	−22	−20	−31	−10	−23	340	315	398	322	165	296
11	7	9	14	7	11	10	−17	−20	−17	−27	−20	−20	348	315	333	308	165	274
12	5	10	13	9	3	8	−10	−17	−13	−21	−18	−16	360	315	328	320	135	292

TABLE 11.—*Vectors of the diurnal magnetic deflecting forces.*

β azimuth angle, N. = 0°, W. = 90°, S. = 180°, E. = 270.
s in terms of 0.00001 C. G. S. unit.
α vertical angle, positive to zenith.

Hours.	January. s	January. α	January. β	February. s	February. α	February. β	March. s	March. α	March. β	April. s	April. α	April. β
		°			°			°			°	
12 a	6	+ 3	258	8	−13	265	9	−11	285	7	−30	290
1	4	+16	388	6	−14	259	8	−19	288	8	−22	295
2	4	+19	296	6	− 9	271	8	−14	291	8	−18	294
3	4	+23	343	5	− 7	279	6	−10	304	9	−12	288
4	5	+14	363	4	− 5	296	8	− 9	298	9	−14	286
5	6	+10	373	7	− 9	305	7	− 9	331	10	−14	285
6	7	+10	365	7	− 3	312	10	−14	339	14	−19	289
7	10	+ 6	354	9	− 2	282	12	−21	311	21	−15	294
8	10	+ 3	321	12	− 4	297	17	−17	278	27	−11	259
9	12	+10	298	12	− 4	292	21	− 2	266	26	+ 1	241
10	11	+21	217	12	− 3	257	20	+14	240	23	+26	221
11	13	+24	176	15	+20	209	22	+35	182	26	+44	161
12 p	16	+20	120	20	+34	105	27	+34	103	35	+34	94
1	17	+ 9	101	21	+26	97	29	+20	95	40	+19	64
2	13	− 7	98	19	+18	89	29	+12	89	36	+12	61
3	8	−21	99	15	+11	89	21	− 2	86	25	− 1	78
4	6	−36	115	10	+ 1	93	12	−14	94	16	−16	84
5	5	−37	131	7	−16	65	8	−31	134	11	−33	100
6	5	−40	120	6	−31	120	6	−28	122	11	−37	140
7	5	−47	207	4	−33	200	6	−31	123	9	−37	131
8	6	−30	264	6	−31	265	7	−29	214	11	−30	285
9	7	−14	260	7	−27	254	8	−28	276	9	−34	289
10	7	− 9	256	8	−22	263	9	−19	269	9	−29	284
11	7	− 7	256	8	−20	260	9	−18	276	8	−26	283
12	6	− 3	258	8	−20	265	9	−11	285	7	−30	290

Hours.	May. s	May. α	May. β	June. s	June. α	June. β	July. s	July. α	July. β	August. s	August. α	August. β
		°			°			°			°	
12 a	6	−31	278	7	−24	278	8	−25	272	8	−16	292
1	7	−36	281	6	−20	281	7	−28	335	8	−14	329
2	7	−20	302	7	−15	282	8	−22	302	8	−18	321
3	7	−19	302	8	−10	291	9	−16	317	10	−11	315
4	9	−17	296	10	−12	286	9	−25	295	11	−12	300
5	14	−16	284	16	−14	286	16	−20	290	15	−19	297
6	22	−13	276	25	−11	275	23	−14	279	24	−16	280
7	26	− 9	263	30	− 5	265	29	−10	265	31	−13	267
8	28	− 4	256	30	0	252	31	− 6	251	32	− 9	226
9	28	+ 7	235	26	+ 7	235	27	+ 5	233	27	− 1	227
10	19	+34	198	22	+29	208	24	+20	208	21	+29	162
11	24	+44	106	25	+36	139	25	+35	139	27	+31	128
12 p	30	+33	97	31	+30	100	29	+30	105	37	+23	96
1	36	+21	81	35	+23	81	34	+21	89	37	+16	88
2	32	+13	73	34	+14	63	32	+14	83	32	+ 9	80
3	23	+ 2	78	28	+ 1	81	26	+ 4	81	21	+ 2	75
4	14	−15	81	19	−12	80	17	−10	78	11	−19	76
5	10	−45	94	14	−36	87	10	−32	87	9	−46	86
6	9	−51	112	9	−53	76	9	−50	111	10	−51	63
7	8	−48	166	9	−49	148	10	−38	96	10	−36	45
8	8	−34	256	10	−46	320	9	−33	312	10	−27	314
9	9	−31	294	9	−36	310	9	−30	299	9	−23	320
10	8	−27	277	8	−33	304	9	−22	292	9	−23	296
11	7	−28	282	8	−27	287	8	−27	277	10	−20	274
12	6	−31	278	7	−24	278	8	−25	272	6	−16	292

Hours.	September. s	September. α	September. β	October. s	October. α	October. β	November. s	November. α	November. β	December. s	December. α	December. β
		°			°			°			°	
12 a	9	−11	323	10	−10	272	9	+ 2	268	6	+10	252
1	6	− 9	333.	6	0	306	7	+ 6	225	7	+16	256
2	10	− 6	322	7	+ 2	319	6	+23	286	3	+26	277
3	10	− 7	317	8	− 1	313	5	+23	322	3	+28	316
4	12	− 9	320	8	+ 1	333	6	+16	331	4	+14	362
5	13	−10	311	9	0	344	7	+17	365	6	+10	364
6	16	−12	300	10	− 7	341	10	− 4	347	7	+ 3	369
7	22	−12	274	14	−16	310	10	− 6	353	9	+ 4	359
8	25	− 8	252	20	−15	274	10	−12	319	11	− 3	349
9	25	+ 2	226	22	− 9	247	10	+14	281	9	+ 6	311
10	21	+20	178	24	+15	214	12	+30	214	7	+22	298
11	29	+27	135	24	+26	168	16	+25	174	11	+27	175
12 p	35	+17	111	29	+24	107	22	+18	96	14	+18	121
1	34	+13	92	32	+16	98	19	+10	94	14	0	111
12	30	+ 1	82	26	+ 9	89	15	− 6	99	11	− 1	109
3	18	−10	77	18	− 6	87	13	−20	115	8	−16	106
4	10	−34	89	9	−34	110	11	−35	116	8	−20	133
5	7	−41	159	8	−36	130	9	−30	142	6	−24	126
6	7	−50	148	9	−42	156	8	−35	116	4	−24	128
7	7	−48	168	8	−51	285	7	−36	195	4	−27	227
8	9	−32	282	9	−36	272	9	−22	256	5	−19	243
9	6	−26	286	11	−23	272	11	−19	259	6	−15	250
0	9	−18	290	11	−20	278	11	−16	265	7	−10	248
1	8	−13	308	11	−15	289	9	− 6	264	7	+ 8	254
2	9	−11	323	10	−10	272	9	+ 2	268	6	+10	252

APPLICATIONS TO THE PROBLEMS OF THE WEATHER.

The foregoing correlation of the connections between the phenomena of temperature, pressure, vapor tension, atmospheric electricity, ionization, and magnetic vectors seems to give a natural unity to these data which have been detached from one another in the previous scientific researches. The entire train of causes and effects is arranged by it in a satisfactory sequence, so that we are for the first time in a position to summarize the masses of evidence lying before us. It will be now possible, having a clear working hypothesis before us, to indicate the proper manner of continuing the investigations with every prospect of reaching a successful practical result. I propose in the remaining papers of this series to lay down a working program for American meteorologists to use, including in that term those astrophysicists who are interested in the sources of our radiant energy, as well as the climatologist and the forecaster who are concerned with the effects of radiation upon climatic and weather variations. The first paper will contain a popular statement of the general conditions; the second, a more technical account of the theoretical aspects of the problem of cosmical meteorology; and the third, a description of the organization of the Mount Weather Research Observatory which is designed to mediate between the theoretical and the practical sides of the subject.

THE SUN A VARIABLE STAR.

In order to bring out the underlying reason for believing that variable solar action is responsible, at least indirectly, for changes in the terrestrial weather from year to year, it is necessary to show in what way the sun is itself unequal in its internal movements. The sun is an immense solid-liquid mass, 866,000 miles in diameter, surrounded by a gaseous envelope which gradually changes to rarefied matter similar to that seen in vacuum tubes. Recent computations indicate that at the center of the sun there is a nucleus which instead of being gaseous is nearly as solid as the interior of the earth, with a temperature of about 10,000° centigrade; the average density of the whole sun is 1.43 times that of water, and this is located at half the distance from the center to the surface; the surface density is not far from 0.37 that of water, and its temperature, according to my calculation, ranges between 7000° and 6000° centigrade; at the surface there is a sudden transition from liquids to gases, which occurs as an explosion, caused by the uprush of liquids from the interior. The solar mass in such a physical state while rotating on its axis sets up a peculiar circulation, in consequence of which at the surface a huge wave is formed like a tide that advances most rapidly in the equatorial belt.

The body of the sun is divided up into layers of different temperatures, like a set of dice boxes inside one another, the longest axis extends through the sun from pole to pole, and these slide by one another at different velocities. This produces a stronger discharge of warm material in the polar regions than near the equator, so that on the sun the heat is greatest at the poles, reversing the conditions with which we are familiar in the earth's atmosphere.

The evidence for these facts is found in a study of the (1) sun spots, which occur in belts within 35° of the equator; (2) the faculæ or fleecy cloud-like forms found on all parts of the sun's surface, but most abundantly around the spots; (3) the prominences or gaseous flames projected in all latitudes above the disk; and (4) the coronas, which extend to great distances from the surface and somewhat resemble auroras in their nature.

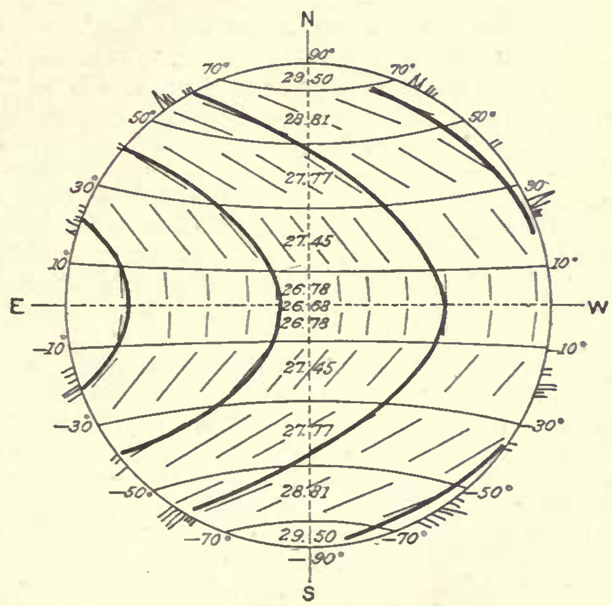


FIG. 64.—Retardation of rotation in different zones of the sun.

The visible surface is divided for convenience into successive zones beginning at the equator as shown on fig. 64, where the advancing equatorial wave is indicated, the time of rotation being marked in different latitudes with 26.68 days at the equator, increasing to 29.50 days at the poles. The time of the rotation of the internal solid nucleus is not known. There are some arguments for supposing it to be 26.00 days, and others for making it 26.68 days, but the subject has not yet yielded to study. The above periods of rotation are those seen from the earth as it passes around the sun in its orbit of 365 days.

Fig. 65 gives an excellent idea of the visible surface. This is mottled with cloud-like forms resembling the heads of cumulus clouds, and probably they represent the tops of columns of liquid or gaseous matter rising from the interior; there are three minute sun spots to be seen on it, and extensive regions of white calcium flocculi in the sun-spot belts. The spectroheliograph has developed the power to make pictures like this at different levels in the sun's atmosphere, representing sections through it, so that the action of the vapors and gases surrounding a spot can be studied at several elevations, just as we make out the cloud forms at different levels in the earth's atmosphere by their types. In this picture the details are quite perfectly brought out.

Fig. 66 is an illustration of a great sun spot and the clouds or the flocculi in its neighborhood. Three or four such section pictures are made one over the other, wherein the forms change gradually from the lowest level to the highest. It is very probable that the true circulation in the region of the spots can be determined by examining the details of such pictures. The sun spots of the winter 1904–5 closely resemble the one in this illustration in size and appearance.

Fig. 67 gives some examples of quiescent and eruptive prominences or hydrogen flames, as observed at Kalocsa Observatory. The forms resemble flash illuminations in clouds dur-

ing storms where no lightning discharge occurs, and are probably due to the light from the photosphere passing through rarefied layers of gas, in about the same way that the aurora illumination is formed. Electrical glow discharges and magnetic forces are probably in operation at the same time. The eruptive prominences are due to uprushes of gas exploding from the surface. The liquids in the interior are at very great pressure and temperature, but on reaching the surface this pressure diminishes suddenly and the liquid explodes into gaseous formations such as are shown. Enormous velocities up to 1000 miles per hour are indicated, and great altitudes up to 300,000 miles above the surface have been noted.

Beyond the limits of the gaseous constituents of the sun extends the corona which reaches altitudes of from 1,000,000 to 5,000,000 miles above the sun's surface. The lower section of fig. 68 gives four typical shapes, one at the minimum of solar activity, one at the maximum, one at the rising, and one at the falling phase. At the minimum the polar region is capped with a ray-like structure in which the streamers bend away to either side, as if they were the lines of force in a magnetic field surrounding a spheroidal magnet. At the maximum of the period the coronal forms are confused and no definite structure is preserved, indicating that some cause is operating to obscure the beautiful magnetic structure seen at the minimum when the sun is not very active. The corona of the sun can not be observed except during total eclipses, but it is found by comparing the forms secured during the past 40 years that it passes through a well defined cycle, repeated in about 11 years, as is indicated in the diagram. The next total eclipse will occur on August 29–30, 1905, and will be visible in Spain and northern Africa. Parties are already being formed in the United States to make observations on that occasion.

The passage from a quiet to a strongly agitated condition of the sun is marked also by other remarkable variations in phenomena which are visible from the earth. The upper section of fig. 68 gives the relative frequency of the sun-spot area as computed at the Greenwich Observatory. A minimum occurred in 1889, a maximum in 1894, and a second minimum in 1900, about 11 years later. The height of the shaded area is proportional to the number of sun spots seen on the sun, and it indicates that the rate of increase following the minimum is more rapid than the rate of decrease following the maximum. Similar curves of sun-spot frequency have been constructed for the last century, and in them it is found that there is considerable irregularity in the curve from one period to another, so that the 11-year period is merely an average of the range between 8 years and 14 years. On comparing the sun-spot curve with the changes in the magnetic and electric fields as observed on the earth, that is to say with the positions assumed by the magnetic needle and with the auroral displays in the polar regions, it is shown that these three systems are in very close accordance, and it is conceded that some relation of cause and effect prevails. The inference that the difference in the number of spots is the cause of the corresponding change in the earth's electricity or magnetism is not sustained by more minute examination of the details, except in a general way. The better theory is that the internal solar action produces all of these phenomena simultaneously, as the effects of an underlying cause which is not yet fully understood.

We can, perhaps, convey some idea of the present state of the investigation in the following way. The difficulty of the research has been due to the fact that the sun spots are only a sluggish register of the true solar action which causes the variable weather conditions, and it has been a great task to discover a better pulse. In 1894 the author published some results of a study of the meteorological conditions in the United States for the interval 1878–1893, in which it was found that the barometric pressure and the temperature vary slightly, not only in an 11-year period, but, also, in a 3-year period which is more clearly defined. In the same work it appeared that the average position of the storm tracks in the United States sways up and down in latitude, and also that the speed with which the storms drift eastward varies in the same short period. The annual magnetic field gives both periods in combination, the 3-year period superposed upon the 11-year period, thus making the inference probable that both periods in the meteorological and magnetic elements depend upon solar operations. Unfortunately the sun spots show us the 11-year period strongly and the 3-year period very feebly. This point has recently been cleared up by a study of the solar prominences, which have been continuously observed by the Italian spectroscopists since 1871.

Fig. 69 shows that great variations occur in the number of the prominences and the faculæ, the former being represented by the red marks on the diagram, and the latter by the blue marks. In the year of minimum activity, 1889, both prominences and faculæ are very few in number, but in the year of

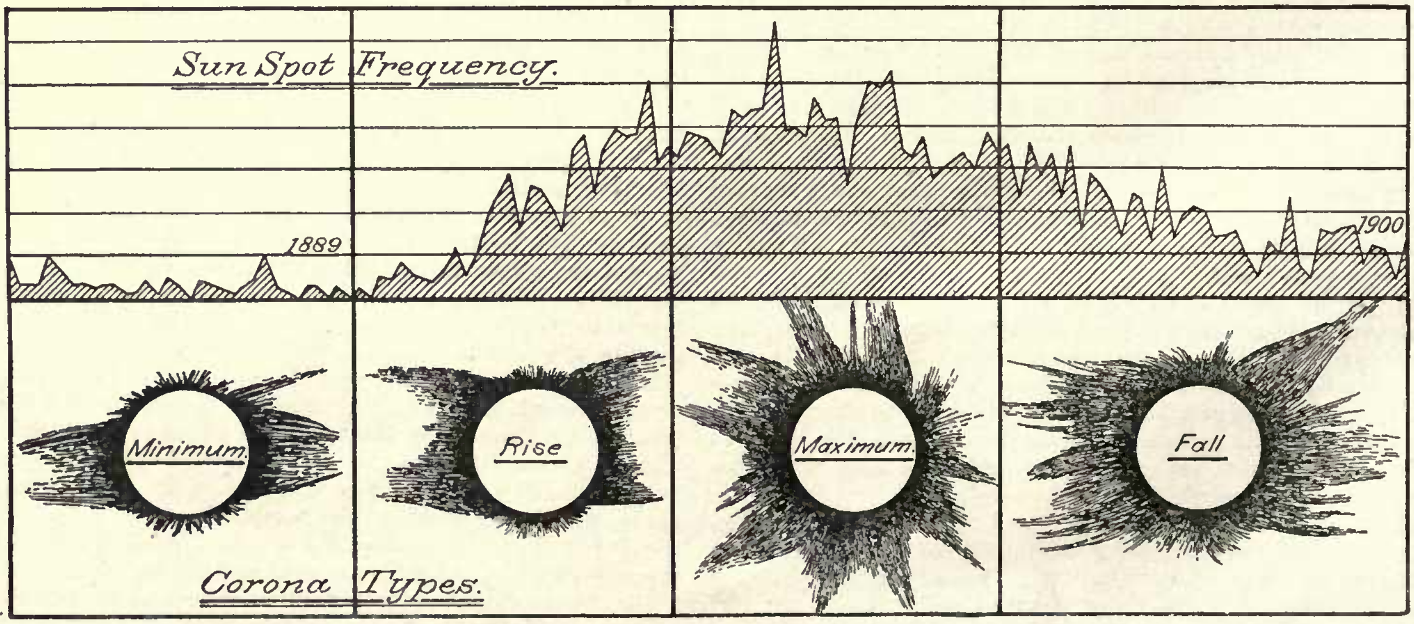


Fig. 68.—The upper section shows the variation in the relative number of sun spots in a 11-year period and the lower section shows the corresponding changes in the form of the solar corona in passing from minimum to maximum and back to minimum.

maximum activity, 1894, they are very abundant in the central zones, the prominences extending into the higher latitudes.

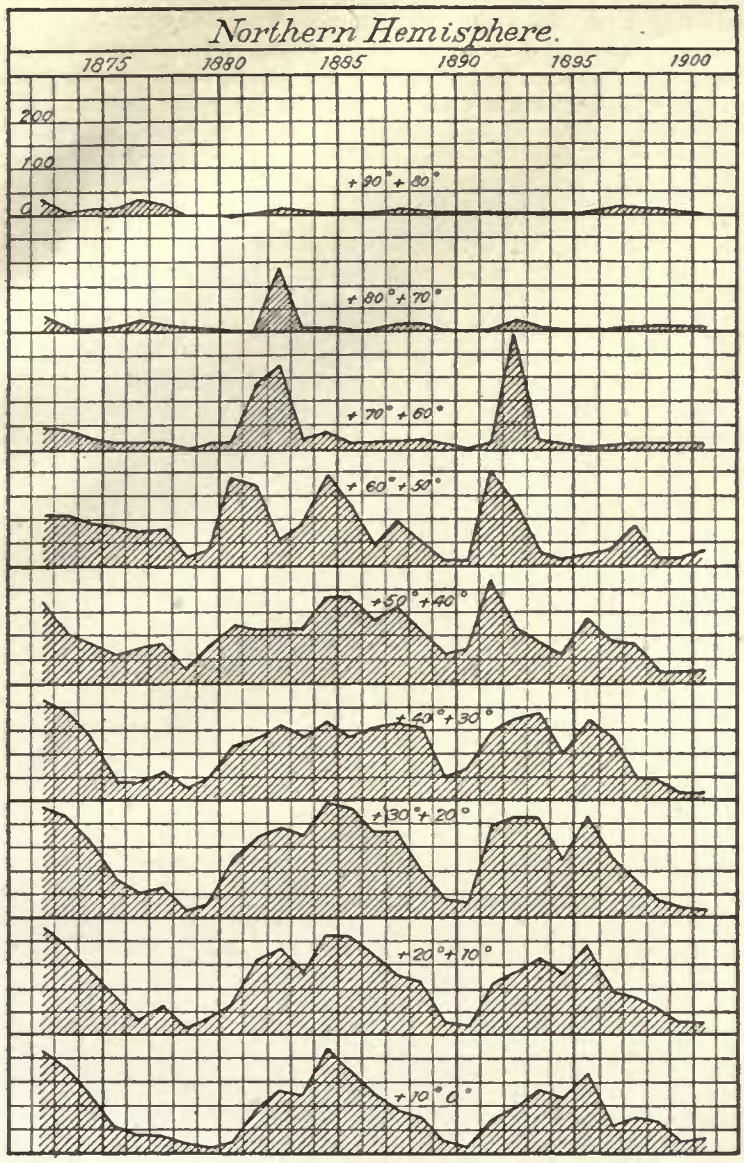


FIG. 70.—Relative frequency of the occurrence of hydrogen flames as seen on the edge of the Northern Hemisphere of the sun in a spectroscope: the distribution on the Southern Hemisphere is similar to that shown on the northern.

These eruptions on the surface of the sun move up and down the solar disk by a law of their own, and this must depend upon the internal energy of the sun, which, like a variable star, is passing through a series of periodic convulsions in its process of evolution. Lockyer, in 1902, published the result of his discussion of the prominences, as they occur in each 10-degree zone between the two poles of the sun. Thus, it is seen by fig. 70, for the Northern Hemisphere, how different the distribution of the prominences is in latitude. In the equatorial regions,[1] where the spots prevail, the 11-year period is very pronounced, though there are signs of the 3-year period in connection with it. On the other hand, in the higher latitudes,[2] the 11-year period diminishes in importance and the 3-year period supersedes it.

THE SYNCHRONOUS METEOROLOGICAL CONDITIONS ON THE EARTH.

Now, it happens that the frequency variation of the solar prominences in the higher latitudes gives the key that was wanted to enable us to study the meteorological conditions in the earth's atmosphere with some prospect of success. This variation shows that the meteorological pulse is registered most favorably not in the sun-spot belts, but in the zones of the sun corresponding with the temperate zones of the earth, from latitude 30° to 60°. In the polar zones in certain years the prominence frequency is very well marked, and these years correspond with the years of special activity in the earth's electric and magnetic fields.

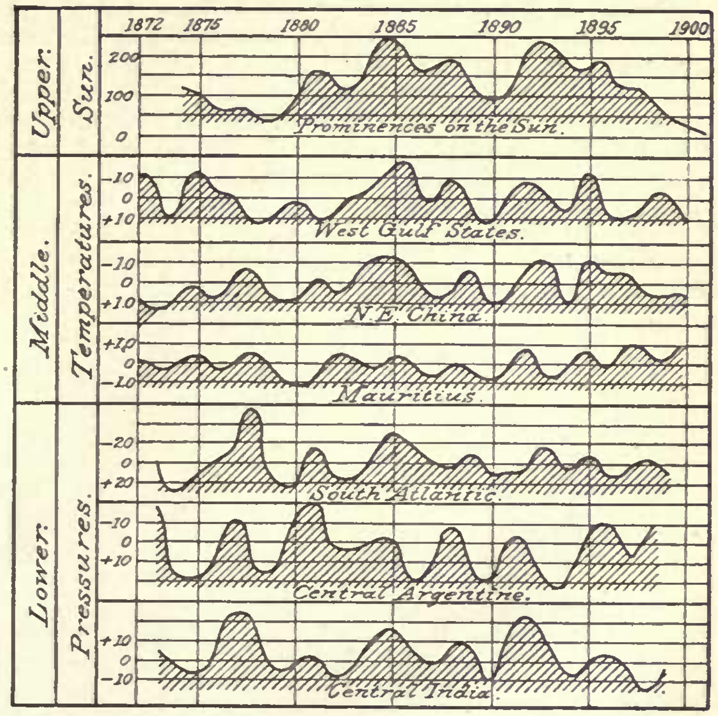


FIG. 71.—Comparison of the annual changes of the prominences on the sun and the temperatures and pressures on the earth during the years 1872–1900.

In order to extend the comparison of the solar-terrestrial conditions further, I computed the annual mean pressure and annual mean temperature for the series of years, 1872–1900, over many portions of the earth, comprising records for several hundred stations. They were grouped together by countries and a few of the curves are brought together in fig. 71. In the upper section of this figure the prominence frequency on the sun is averaged for all zones, and the resulting curve contains a 3-year period superposed upon the 11-year period. The middle section, marked "temperatures," contains temperature curves from the tropical and temperate zones, and it is easily seen, by comparing the crests with the solar curve at the top, that in spite of some irregularities there is a tendency to form the same number of crests and to make them fall on the same years as the crests in the prominences. The third section, marked "pressures," gives a few curves of the variations in the annual pressures and these conform quite closely to the same system. Each curve ought to be compared with the solar curve by itself, to judge of the general fact of agreement. It should, however, be observed that this agreement is not everywhere direct, but that in certain regions an inversion takes place. Thus, the pressures do not increase simultaneously all over the earth in one year and decrease in another year, rather there is a general surging by which the atmosphere is piled up in one region and lowered in another during the same year. This is necessary in order to avoid the difficulty of making the total weight of the earth's atmosphere vary from year to year. When the pressure is generally high in North or South America, it is low in Asia, the Indian Ocean, and Australia. This

[1] Zones, (+ 10° 0°), (+ 20° + 10°). (+ 30° + 20°).
[2] Zones, (+ 40° + 30°), (+ 50° + 40°), (+ 60° + 50°).

condition is brought about by some profound modification in the circulation of the earth's atmosphere, by which high areas tend to form in one hemisphere at the same time that low areas prevail in the opposite hemisphere. In a similar way the changes of temperature from year to year are such that in the tropical zones, where the sun shines fully on the earth's surface, temperatures rise and fall directly with the solar prominence frequency; but in the middle latitudes of the earth the opposite or reverse conditions of temperature prevail. Hence, when solar activity increases and more spots or prominences can be seen, there is an increase of heat in the earth's Tropics, and this produces an increase in the circulation of the entire atmosphere. The warm air of the Tropics rises more rapidly than usual, the cold air of the upper strata over the temperate zones pours down vigorously upon the United States, Europe, and Asia, and these countries are covered with a rapid succession of pronounced cold waves, such as have marked the years 1904 and 1905.

The increase in solar activity shows itself in yet another way. By putting together the tables of prominences so as to study their behavior in longitude, that is around the sun in the same zones, it has been found that the retardation of the solar rotation in the higher latitudes relative to the primary equatorial period of 26.68 days, sways backward and forward in harmony with the same prominence frequency curve. This indicates that the internal solar energy, in trying to free itself after accumulation and congestion, sends forth great waves, which rotate the circulation in the polar zones farther backward. The visible symptoms of this operation at the surface are changes in the number and location of the prominences, the faculæ, the sun spots, the granulation of the photosphere, and in the form and extent of the great coronal streamers. Besides this visible effect of the internal action, there is the more important and invisible radiation which streams from the sun and falls upon the earth.

Besides the general synchronism in the solar action just outlined, we have a corresponding movement in the earth's atmosphere embracing the magnetic and electrical forces, the pressure, temperature, vapor tension, and precipitation. Conflicting evidence will no doubt be reconciled by a more thorough study of the underlying facts of inversion, and generally the entire subject needs most careful investigation.

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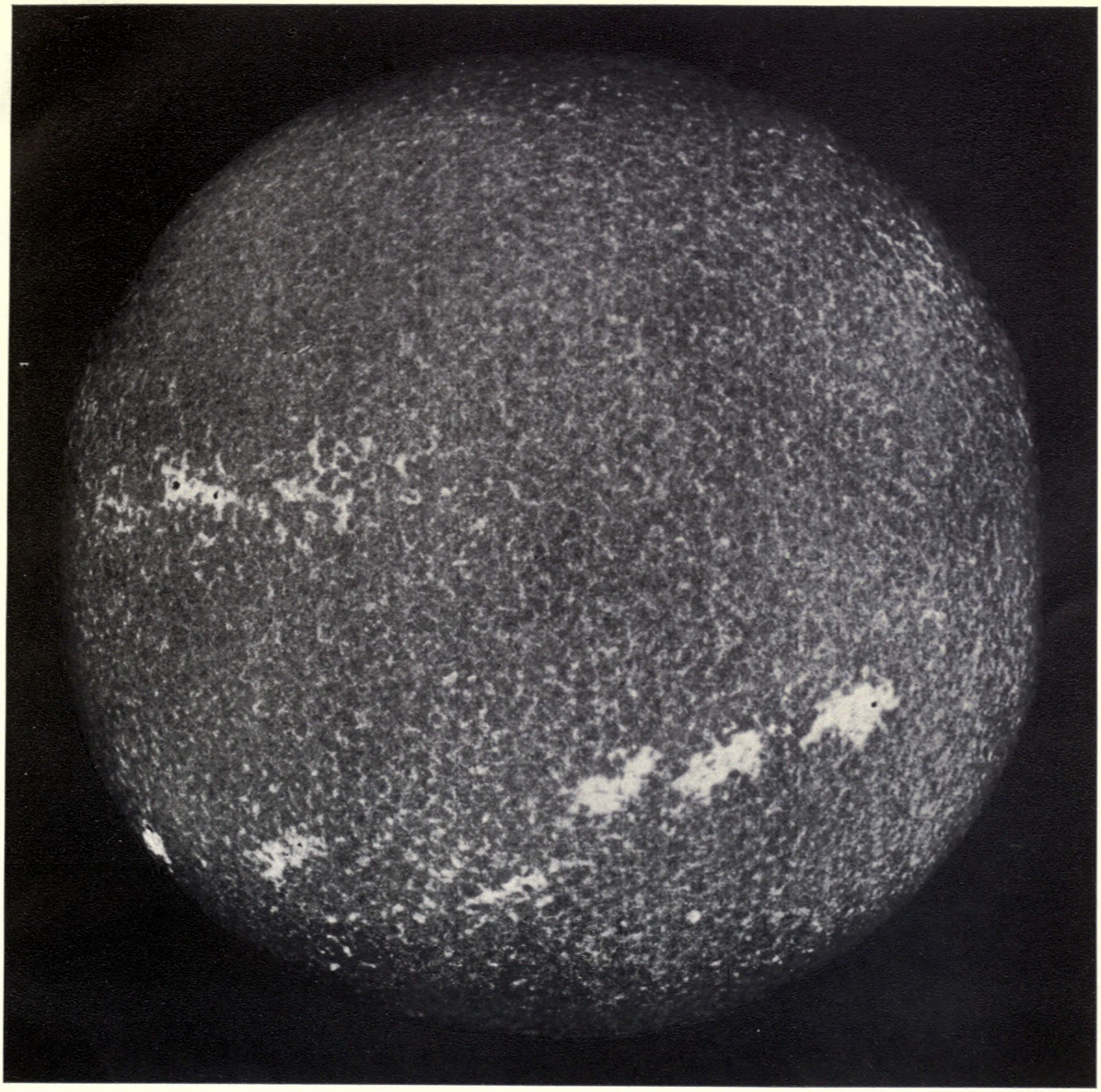

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FIG. 65.—Spectroheliograph of the sun, August 12, 1903, taken at the Yerkes Observatory, showing the spots, flocculi, and general appearance of the bright surface of the photosphere.

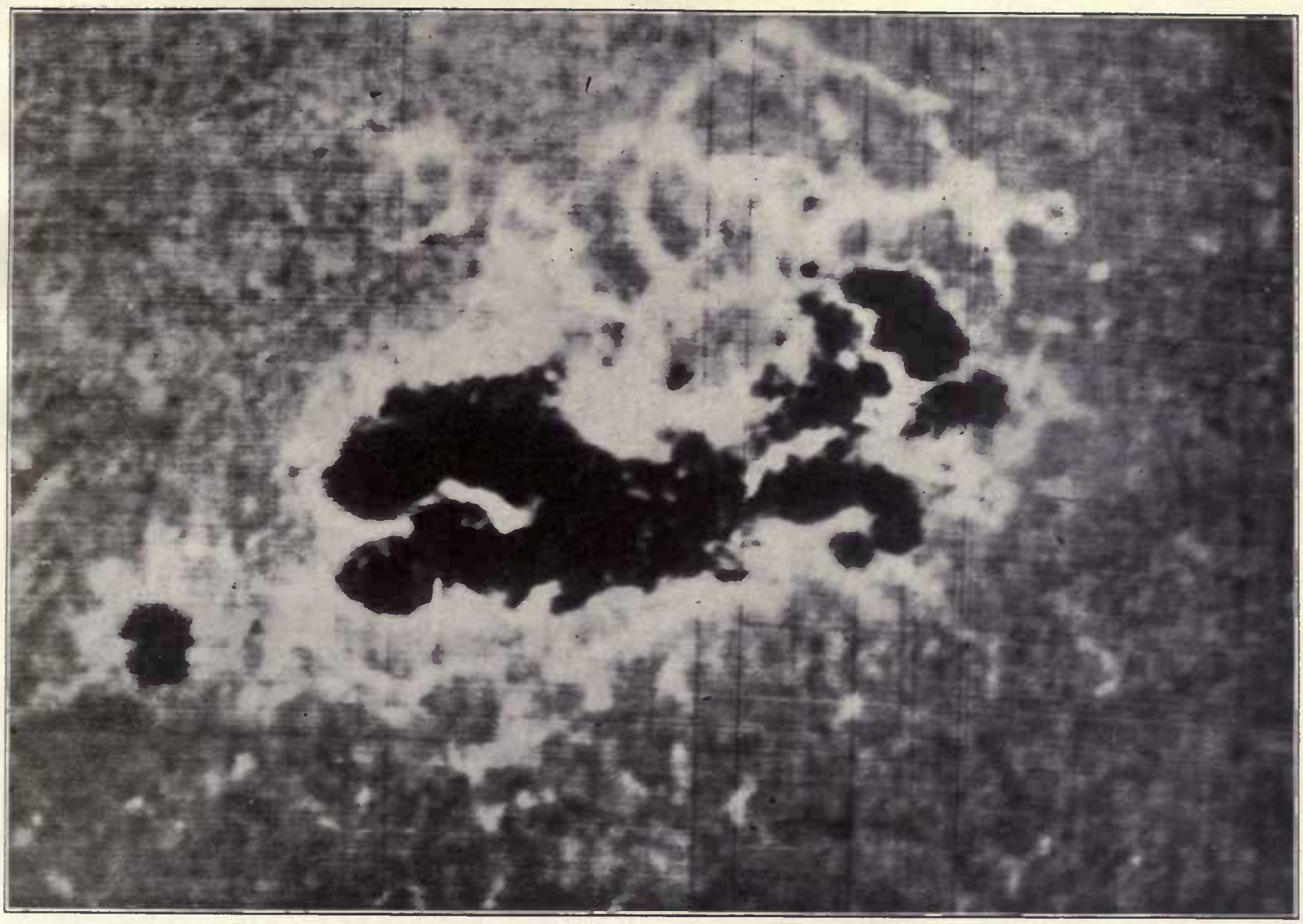

FIG. 66.—Spectroheliograph of the sun spot of October, 1903, showing the calcium flocculi surrounding it.

FIG. 67.—Typical forms of the solar prominences or red hydrogen flames.

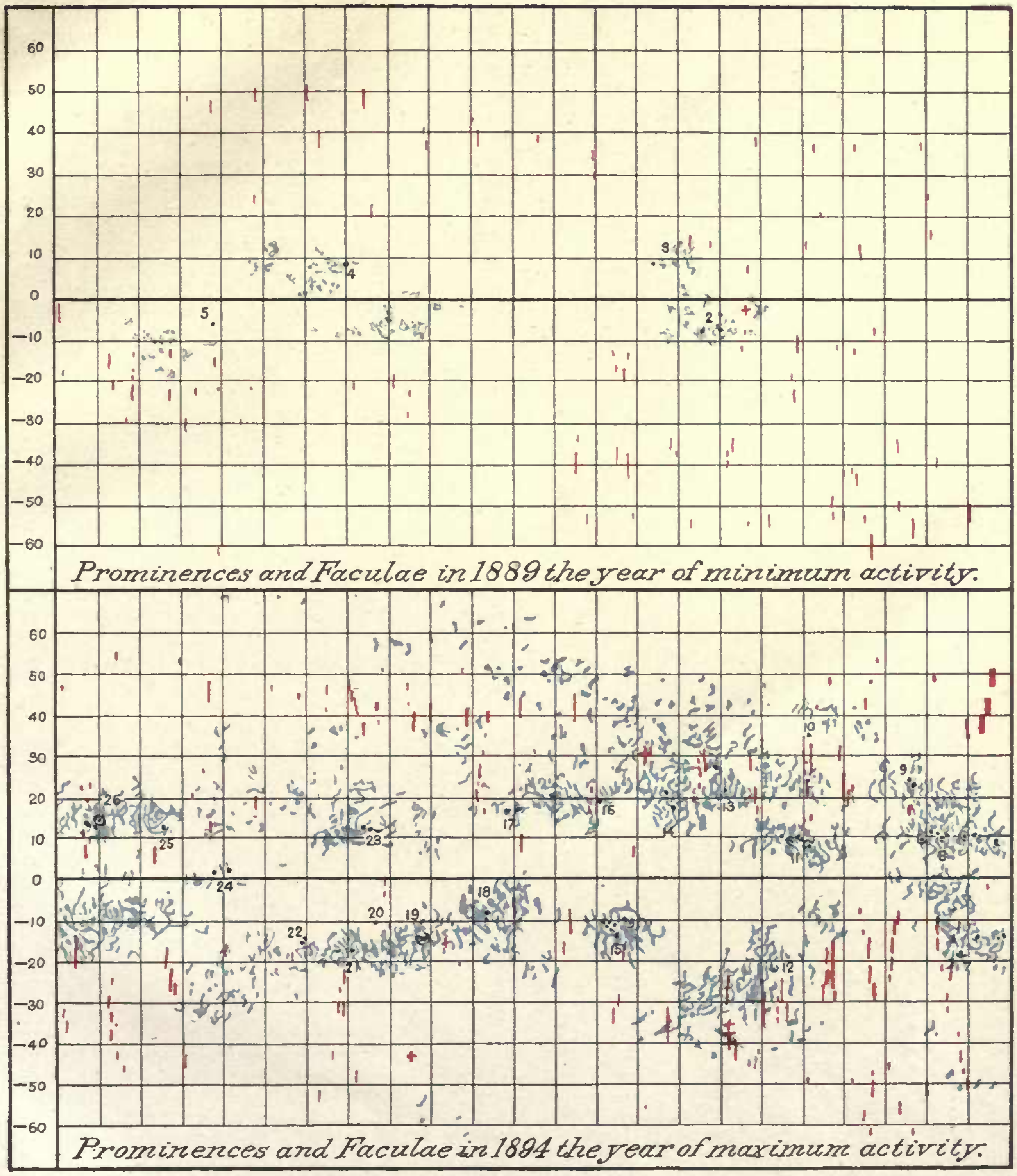

FIG. 69.—The frequency and size of the faculæ and the prominences change from year to year, as shown by examples from the minimum in 1889 and the maximum in 1894. Faculæ in blue. Prominences in red.

VI.—GENERAL REVIEW OF THE STATUS OF COSMICAL METEOROLOGY.

COSMICAL METEOROLOGY.

A great advance is taking place in the science of meteorology, and this has been brought about during the past fifteen years. It has been due to two causes, the growth of modern physics, and the extension of observations into the strata of atmosphere high above the ground. The new theories of the constitution of matter, in which the emphasis is laid upon the electrical nature of the ultimate units of which atoms and molecules are constructed, and the transmission of energy in ether waves across great distances, have disposed the scientific world to examine old conclusions from a very different point of view.

(1) In 1890 the high temperature of the sun seemed to justify its exclusion from the class of magnetized spheres, and thus to separate it from the group containing the earth. Now, however, there are numerous arguments which make it necessary to reconsider that view, and to admit that the sun is probably a highly magnetized sphere which sustains a magnetic field embracing the earth in its action.

(2) Then the radiation from the sun was considered a constant quantity, but now, there are so many lines of converging evidence to show this may not be true, that the subject has become one of serious investigation, and the belief is widespread that the sun is a variable star transmitting its energy to the earth in such ways as to produce synchronous changes in its meteorological and climatic conditions.

(3) In those days the theories of the general circulation of the atmosphere, as formulated by Ferrel, were generally considered to be correct, but the explorations of the atmosphere, by means of theodolites, nephoscopes, kites, and balloons have seriously discredited all except the central idea.

(4) In the same way, the Ferrel theory as well as the Oberbeck theory of the circulation of the air in local cyclones and anticyclones, have both become obsolete and a new type of vortex is being considered as applicable to them.

It is evident that a reconstruction of ideas is in order all along the line, and that meteorology is passing through a transition period in its development. The general outcome is to raise meteorology from a subject which was the peculiar property of the climatologist and the forecaster into one of vital interest in cosmical science, and, indeed, one which is essential to the progress of astrophysical astronomy. This change from an empirical and statistical basis, requiring merely clerical functions in those practising the art, to a plan of operations involving the highest ranges of astronomy, mathematics, and physics in its students, is one of the most hopeful signs of the times. Meteorology has really languished for the lack of a demand for high grade scholarship, but the knowledge that the observations of pressure, temperature, vapor tension, and vectors of motion in the earth's atmosphere have an astronomical value, will, of course, facilitate the introduction of methods of precision in the observations and in the computations leading to a discussion of the results.

The research that is bringing about this change in meteorology has been one of extraordinary difficulty for two or three reasons. In the first place, by the very nature of the case, meteorology must depend largely upon handling great masses of data, at least till a higher stage of classification and unification of the laws has been attained, because the action of the several elements differs greatly from one station to another over the earth, and each station must be considered on its own merits. In astronomy, on the other hand, a ready concentration of observations, made in various places upon the same celestial object, is practicable, and this coordination leads more rapidly to a final set of constants and formulæ. The astronomical ephemeris, embracing the positions of the sun, moon, planets, and stars, with their characteristic phenomena, are, thus, readily made up, and by successive comparisons between predicted and observed places a progressive accuracy has been developed. Meteorology has not yet attained the dignity of the most elementary kind of ephemeris, but has been content with striking a rough mean or normal from a large mass of crude observations. This method has no doubt been sufficient for climatological statistics, and for such forecasts as have been attempted during the past, but with the entrance of cosmical problems into the field of work that sort of procedure is entirely inadequate.

A METEOROLOGICAL EPHEMERIS.

As already mentioned, the first line of improvement, having in view the ultimate construction of a true meteorological ephemeris, is a careful discussion of the existing data. An examination of the available observations in the various portions of the earth, convinced me several years ago that for cosmical meteorology they are well nigh valueless in their present state. There has been an incessant change in the conditions under which the observations were made, following the exigencies of administration, or in consequence of the lack of scientific purpose and method in conducting the reductions. Thus, the hours of observation have been changed, and this has broken up the homogeneity of the series; the elevation of the station has been frequently altered; the exposure of the instruments to the weather has been modified, often radically, by the growth of our large cities; hence it is that a pure series of data extending over several years is not a common feature of any meteorological service. The ephemeris of this science must take account of a list of natural phenomena different from that found in the astronomical almanacs, namely, the pressure, the temperature, the vapor tension, and the wind vectors in the atmosphere of the earth, at the least; the frequency of the spots, the faculæ, the prominences on the sun; the intensity of the lines in the spectrum, distinguishing those of solar from those of terrestrial origin; the relative absorption of the radiation in the solar and the terrestrial envelopes, respectively; the strength of the electric and the magnetic fields in the earth's atmosphere, including the auroras, the ionization, the electric potential, and the coefficient of dissipation. In all these cases, for the construction of an ephemeris, it is not sufficient to strike a mean value from a series of observations extending over a number of years, where the individual years are not homogeneous one with the others. What we want is a series of correct yearly and monthly residuals relative to a central normal or mean value, wherein it is certain that the apparent

variations from year to year are not due to faulty instruments and inadequate modes of observing, nor to incorrect and insufficient methods of computing. There is an immense mass of meteorological data which in its present state has no value for a cosmical science, because the accidental errors, that is those which can be controlled and ought to be eliminated in forming a truly homogeneous series, are larger than the residuals which can correctly be attributed to the variable solar action. *The margin of variability induced at the earth by the unsteady energy of the sun is quite narrow, and there is nothing to be squandered by poor workmanship if any useful results are to be accomplished in practical meteorology.* There is nothing scientific in attributing to the sun's action those changes which pertain to the inaccurate observer or to bad methods of working the instruments, nor is there any justification for comparing good solar observations with bad meteorological observations. If cosmical meteorology is to be established then all rough and ready methods must be abandoned, and the work of computing and discussing the data must be placed in the hands of physicists and astrophysicists who possess scientific instincts and training. It is only by acquiring long series of accurate residuals in all the elements enumerated above, that is to say exact values for each month and year at the selected standard stations, that a suitable ephemeris can be constructed. Upon the successful accomplishment of this purpose depends the establishment of cosmical meteorology and the detection of the laws controlling the many interrelated forces which culminate in weather and climatic conditions. I maintain that the seasonal and yearly changes in climate, which each country experiences, depend upon the variable output of the solar energy, as recorded in the circulation of the sun's atmosphere and in our own atmosphere, and the sequence of these variations is a proper subject for scientific examination. This work in one sense is common to the entire earth, and yet each country has its own climatic effect to be accounted for in the general integration. No country can transfer its task to another, and each has enough to do to take care of its own observations. To some extent international cooperation is desireable and practicable, but on the whole each climatic region must work out the problem for itself. There is a common solar-terrestrial circulation which flows throughout the entire cosmical system, yet each country has a pulse of its own, and this must be discovered and analyzed before there can be any expectation of establishing an efficient seasonal meteorology.

THE PRESENT STATUS OF THE REDUCTIONS.

My own work has for many years been concerned in reducing the crude meteorological data for the sun, the earth generally, and especially for the United States, into standard conditions, from which the first approximately correct residuals may be attained. The task has been far beyond my power, with the resources at command, and the work is not yet finished. Thus, (1) from 1878 to 1893 the magnetic vectors have been properly computed, but they had to be extended by graphic methods back to 1841 and forward to 1903 in order to get even a glance at the fundamental law. (2) The diurnal magnetic vectors were worked out for 30 stations and they are in good order. Neither of these works have been published. (3) The pressures for the United States, 1873 to the present time, have been thoroughly recomputed and they are in a satisfactory state. (4) The temperatures are in process of reconstruction, but the task is much more difficult than in the case of the pressures and the work is not finished. (5) The reductions of the vapor tensions are being carried along with that of the temperatures, and they are only partly completed. There have never been any vapor tension normals available in the United States. (6) All the data of atmospheric electricity are in a chaotic state and need complete revision. (7) The ephemeris of relative sun-spot numbers is in good condition in consequence of the work of Wolfer. (8) The prominences and faculæ have been thoroughly discussed by me, but the results have not been published. (9) In the variation of the spectrum lines, and in the variability of the solar radiation as disclosed by the actinometer and bolometer, it has only quite recently been recognized that there is a real problem to be worked out, and we have as yet no true series of observations to classify.

It is evident from this statement that for the United States, where this plan of reducing the observations has been systematically in operation for several years, there remains much computing to be done before we can begin to put our meteorological ephemeris together. Until this is accomplished there can be no attempt to take up the problem of seasonal forecasting, and the quicker this work is finished the better for science in all its astrophysical branches. For it is quite probable, judging from the exposition contained in the preceding papers of this series, that there exists a beautiful yet sensitive network of forces reaching from the sun to the surface of the earth, by which we can learn to read the signs of the climate, and we may hope to be able to learn to forecast it somewhat in advance by a natural system of extrapolation. In the midst of this concatenation of forces the terrestrial magnetic field stands out as the best unifier or integrator. It is the most sensitive and delicate pulse which we possess, having one throb in the solar mass, and the other in its synchronism with the earth's meteorological elements. We shall, then, in our further discussions, use this magnetic system as the proper one about which to group all the other elements which are correlated in this great solar–terrestrial complex.

THE SUN AS A MAGNETIZED SPHERE.

The radical change, gradually brought about by numerous physical researches in our ideas regarding the ultimate constitution of matter, by which we conceive of atoms as composed of dynamic structures of balanced rapidly rotating electric charges, has, also, materially modified the attitude of mind in which we approach the problem of the magnetization of large rotating heavenly bodies. When the atoms were regarded as hard, highly elastic, nonelectrical, and nonmagnetic spheres moving by the laws of kinetic energy in straight paths, except for the effect of collisions, it was of course difficult to prove that the sun could be magnetic of itself at the high prevailing temperature. But if the integrated forces are to be derived from electric charges in very rapid motion, and this seems to be the case, then magnetic fields are essential to the existence of every kind of matter whether in large or in small masses. Under ordinary conditions the primitive motions of the ionic charges are highly disorganized, since the motions are in every conceivable plane, and the molar or large masses do not show any outside field of force. It is, however, only necessary to organize these ionic motions relative to one plane, that is, to polarize their orbits, in order to produce a common magnetization within the mass and magnetic field outside this body. When a steel magnet is subjected to heat the field is destroyed, simply because the minor magnets, as of the atoms and molecules temporarily oriented to one axis, have been made disordered by the higher class of collisions which has been induced by the increase of the temperature. This experiment, however, by no means exhausts the natural conditions of the problem. In a rotating body like the sun the angular velocity induces a deflecting force at right-angles to the momentary motion, of every particle, $l = \omega q \cos \theta$, depending on the angular velocity, and polar distance velocity in any linear direction. When q is great, and in the case of the negative ions combined in the

atom, it may approach the velocity of light, l is also a comparatively large force, so that a tendency to run into vortex motion is ever in operation. The entire mass of the sun, by the general laws of motion, also is evidently organized as a great vortex about the axis of rotation, and these two impulses doubtless tend to polarize the motions of the individual atomic ions in planes perpendicular to this axis, or to produce magnetization nearly parallel to the axis of rotation. Since the movement of the negative ions is in excess of that of the positive ions, the resultant magnetic field will be due to this excess of the action of negative electric charges above the positive charges, since for a common direction of gyration the positive and negative charges produce oppositely directed magnetic field. Finally, if the negative charges, in the atomic conflict, tend to escape from their electric bonds and to roam in disregard of any structure, then these negative charges may well tend to accumulate as an electrostatic layer on the surface of the sphere. At least the negative body-charge may, as a whole, be located farther from the center of the sphere than the positive body-charge, and this will produce internal magnetization and surface electrostatic charge, such as the earth possesses, and such as we have evidence to indicate that the sun also possesses. This dynamic view of mine comes to the same result as the static theory explained by Sutherland.[1] With this introduction I shall merely mention various results obtained in my researches, which are at least circumstantial evidence that the sun is a highly organized magnetic body, and that the numerous variations in its internal action constitute the causes for the observed changes in the external magnetic field.

(1) The polar rays of the corona, at least at minimum, conform to the normal lines of magnetic force on a sphere seen in projection and concentrated in a ruffle at some distance from the pole.

(2) The ions in the solar atmosphere are luminous along rays of magnetic force.

(3) The coronal poles are located asymmetrically with respect to the axis of rotation and persist from one eclipse to another in the same relative positions.

(4) The sun's external magnetic field, as measured at the earth, is so arranged that it has greater intensity in some solar longitudes than in others.

(5) By using large masses of observational material, the typical curve, attributed to difference in solar output in longitude and depending for its existence upon the structure of the sun's nucleus, has been found to be reproduced approximately, in the distribution of the sun spots and prominences in longitude, in the terrestrial magnetic elements, the electric field, the barometric pressures, the temperatures, and the local cyclonic movements in the United States.

(6) There is evidence that the periods of rotation in the higher latitudes of the sun fluctuate about a mean value synchronously with the external energy variations, showing that the entire external system is a direct effect of the forces producing at the same time the interior circulation in the mass of the sun.

(7) The inference is that the sun's magnetic field embraces the earth, and reaches it in lines perpendicular to the ecliptic, falling upon the polar regions of the earth along the planes of the magnetic meridians.

THE RADIATIONS OF THE SUN.

The electromagnetic radiation of the sun transports to the earth the other kind of energy which is concerned in the temperature excess prevailing in the Tropics over that in the polar zones, and produces the observed general and local cyclonic circulations. The coronal rays, especially in the equatorial belts of the sun, indicate that there are other forces in operation in the neighborhood of the photosphere besides those already mentioned.

(1) The spreading of the great streamers away from the plane of the ecliptic suggest an electrostatic repulsion.

(2) The streams of ions, under the action of the mechanical pressure of light, move not in radial lines, but in curves as determined by the additional magnetic and electrostatic forces prevailing in the surrounding space.

(3) It is impossible to assert that enough ions reach the upper strata of the earth's atmosphere to produce the observed variations of the terrestrial-magnetic and electric fields as registered in the lower strata, and it is not probable that this is the fact.

(4) This radial radiation of the photosphere may be to some extent variable in its output, and so produce seasonal climatic temperature and weather variations synchronous with it, as registered in the pressures and temperatures in different regions of the earth.

(5) The normal equilibrium of the earth's atmosphere is probably disturbed frequently, from day to day and hour to hour, by the interplay of this complex system of correlated forces.

THE METEOROLOGICAL EFFECTS OF THE SOLAR ENERGY.

The problem of discussing the effects of the solar radiation upon the magnetic and the electrical fields of the earth's atmosphere, and their relations to the meteorological elements, has been greatly simplified by the results of the research contained in the first four papers of this series. It has been shown that a different correlation of the quantities in consideration can be made and that in this way the intractable conditions which have so long puzzled scientists are decidedly ameliorated.

(1) The fact that there is no one synchronism common to the entire earth between solar and terrestrial causes and effects, has been explained by showing that the temperatures synchronize directly in the tropical zones, but only inversely in the temperate zones, in consequence of the inverting effects of the general circulation; and that while the pressures in the Eastern Hemisphere respond directly to the solar impulse, they surge inversely to it in the Western Hemisphere. Similarly, the precipitation and the local circulation will have to be distributed by regional conditions in the final interpretation. This will reconcile much data that are apparently in conflict as evidence regarding the existence of synchronism generally.

(2) The discovery of ionization in the gases of the atmosphere, generated probably by the short-wave radiation, and the determination of the several types of the temperature waves in the lower strata of the atmosphere, lifts the veil from the problems of the diurnal barometric waves, the electric potential gradient, and the rate of change in the electric charges. These seem to be direct consequences of the temperature acting upon the density of the air in the different strata, and upon the locality, whether warm or cold, sought out by the ions.

(3) The cause of the *hourly* variation of the magnetic field is plainly shown to reside in the movements of the ions from one level to another. The cause of the *daily* variation of the magnetic field is probably in large part due to the movement of the ions from one hemisphere to the other, which at the same time produce the auroral displays simultaneously in each hemisphere, and the electric earth currents as local effects in the several portions of the circuit. This change of view relieves us of the difficulty of making the sun the source of all the energy displayed in a large magnetic storm, since the initial impulse is due to that portion of the energy disturbing the normal terrestrial equilibrium, while much of the observed effect is due to the motion of the ions in a closed terrestrial

[1] A possible cause of the earth's magnetism, W. Sutherland, Terr. Mag. June, 1900; September, 1900; December, 1904.

circuit. It remains to discover in what proportion the energy should be distributed among these three sources, the polar magnetic field of the sun, the variable radiant energy, and the terrestrial ionic circuit.

(4) It is now apparent that in using, for the basis of my original research, the magnetic field of the earth as a register or solar pulse recorder, I have been amply justified in tracing out through it as the intermediary the synchronism between the solar surface variations, shown by the spots, faculæ, and prominences, and the temperature and pressure effects at the earth, because it is in fact an intermediate effect, and evidently the most sensitive one with which we have to deal. The subtile influences of the invisible solar radiation may be registered in several ways, as bolometric spectrum curves, as actinometer integrations, as visible energy spectra, or they may be recorded as elastic potential effects and as magnetic force vectors. The latter are the most persistent in all kinds of weather, and most available for continuous observations. It is only necessary to determine what the connecting functions are in terms of magnetic force, to infer from the magnetic intensity what are the temperatures within two miles of the ground, in the midst of the cyclonic actions, to estimate the movement of the ionic currents, and to determine the relative amount of the incoming solar radiation, and thence to learn much regarding the variable nature of the circulation within the rotating mass of the sun.

(5) It is now easy to see that several lines of scientific inquiry as to the period of the solar rotation have been misdirected. The attempt to associate magnetic storms with the solar spots has failed, because the effective surface radiation on a given meridian of the sun may or may not be associated with a large spot, which clearly depends upon the internal circulation for its existence. Besides this, the magnetic storm is in part dependent upon distinctly terrestrial conditions. The application of Schuster's periodogram to the magnetic declination, in order to determine the periodicity of the solar residuals, was incorrect for this reason. While the magnetic declination varies with the season of the year, and from one year to another, as a consequence of the solar radiation, this component is really a term in the hourly vectors only, due to the vertical rise and fall of the ions from one stratum to the other. On the other hand the horizontal and the vertical components are the only ones which the terrestrial ionic circuits between the two poles will affect, while the declination is wholly subordinate. The rotation of the sun on its axis will in any event, whether the energy is transported in the oval polar circuit or as a linear radial radiation, not much influence the declination from day to day. It was a misapplication to assert that negative results of the periodogram carry with them a decisive critical meaning regarding any solar period. This tendency to mix up terrestrial and solar data in the same mass of numerical quantities, has been also found in the count of the number of the solar prominences, and is no doubt to some extent unavoidable since in our common observations we are not readily able to distinguish between them, but it is my opinion that in the present stage of the science it is better to employ a simple comparison of the data as they stand for the discovery of synchronism and periodicity, rather than to bury the several impulses in one massive computation. What is at present urgently required in this research, is to bring together all the data in simple homogeneous series, as in a carefully constructed ephemeris, for each of the several elements of the entire problem, determine what is solar and what terrestrial, and then introduce terms in the functions which will give some chance of separating the unknowns in a satisfactory analysis. This result will best be reached by intelligent cooperation, and I have no doubt that practical methods may be devised by means of which this purpose can be accomplished. It seems to me a very important advance to have gained a general view from which to correlate and harmonize so many of the problems that have heretofore been insoluble. It will, in conclusion, be proper to give some account of the instrumental apparatus available for the future progress of the research, and to add after that a brief description of the Mount Weather Observatory.

THE GENERAL ORGANIZATION OF THE RESEARCH OBSERVATORY.

In organizing the work of an observatory appropriate to this research it is evident that the demands of meteorology in the United States naturally divide its activities into two classes.

(*a*) The first pertains to education and miscellaneous minor problems, and the second to the solar-terrestrial meteorology whose object is to advance the possibilities of daily and seasonal forecasts. The ordinary collegiate instruction in meteorology will probably be limited to climatology and elementary principles in general meteorology, until a practical application for such knowledge can be found outside the activities of the Government service. The great expense of collecting numerous simultaneous observations will no doubt preclude commercial enterprises in that direction, so that forecasting in the United States will always be confined to the U. S. Weather Bureau. In large manufacturing plants a knowledge of weather conditions is becoming more essential to successful business, so that a demand is likely to arise for well trained men in that direction. For our own service the exigencies of modern science are rapidly outgrowing the capacity of men unskilled in mathematics and physics to keep up with the advanced problems, and it is necessary for the Government to undertake the training of its own experts in the higher meteorology. The time is not far distant when each large city will require the presence of a skilled scientist in connection with the local office, especially as the universities are inclined to cooperate in the way of lectureships in connection with the courses of instruction in physics and geology. It is hoped that at Mount Weather the resident students may be employed as assistants in the various lines of work, and that an immediate contact with the highest lines of research to be inaugurated will make them understand and appreciate the requirements of physical research work. A good physical laboratory is to be constructed, the purpose of which is to afford an opportunity to train men in research methods, and to investigate the numerous problems arising in meteorology.

(*b*) The second division of the work embraces the operations of the solar physics observatory, the magnetic observatory, the balloon and kite plant, and should be operated as a unit, because the cosmical problem has branches in each of these realms of physics, and they can not be separated without injuring the progress that is to be expected from their cooperation. The primary policy of this investigation is to be determined by the fact that the energy effective in producing weather of short periods and climate of long periods, consists of solar terms and terrestrial terms, which are very closely interwoven, but must be separated from each other. In the process of disentangling the solar and terrestrial terms, respectively, the functions connecting the several phenomena, or the physical relations between them, must be carefully studied. At present the entire subject is in confusion, and no deliberate attempt can be made to work up the relative values of the several forces until the observations of the several kinds are placed side by side for comparison. The establishment of suitable series of homogeneous observations in the several branches is the first work of such an observatory. We have so recently become convinced that there is a genuine solar-terrestrial problem for the meteorologist to investigate, that but little definite has been done in putting such a comparative work in operation.

The numerous contributions to the general subject from all portions of the world are absolutely bewildering in their complexity, and we can not expect to make any serious advances unless the details of such observations can be classified in one far-reaching, comprehensive scheme. The observatory must be organized like an army, with a general supported by officers who will execute the several parts of the operations required in the plan of campaign. I shall attempt merely to enumerate, in the next paper, the instrumental methods that it is proposed to employ at Mount Weather, so far as experience shall prove them to be practicable. Every stage of the instrumental work, and that of the reduction of the observations, will imply that first-class training is required, and of course the actual success of the enterprise will depend almost entirely upon the number of expert scientists that can be procured for such a service. As stated above, the margin is not large upon which we can do the solar work, owing to the diminished effects at the earth of the sun's variations, due to its great distance from the earth, and we must waste nothing by using bad methods of work and unskilled men, if any profitable result is to be secured. Poor workmanship and untrained men are barred by reason of the rigorous scientific demands that are placed upon these operations by the natural physical conditions which prevail in cosmical meteorology.